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Title: AUTOMATIC PROBER FOR THE DC CHARACTERISATION OF
           GALLIUM ARSENIDE DEVICES:- PART TWO, THE DATA SORTING
           AND DISPLAY FACILITY

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ABSTRACT

    The Automatic Device Probing System used in the Microwave
Devices Division (DP2) comprises separate measurement and data
handling facilities. the measurement facility is described in
RSRE Memorandum 4065 and the data sorting and display facility
forms the subject of this memorandum.

    The facility described is designed to assist in analysing
the large quantity of measured data obtained from device wafers
and allows general trends as well as individual device parameters
to be investigated. Programs have been written to produce maps
which allow parameter variations across wafers to be assessed and
additional routines are available which present the data in
histogram form. These options allow the numeric as well as the
geographic distribution of the data to be investigated. Three
main types of map display are available, these display the
variation in magnitude of a device parameter across a wafer, the
location and nature of the failure of any failed devices and the
location of devices with a specified combination of parameters.
The histogram programs allow the data range and class interval to
be adjusted enabling estimates of yield and process control to be
made. For measurements such as Capacitance/Voltage on Schottky
test patterns or current/voltage on active devices plots of the
measured data can be displayed. Routines are available which
allow curve fitting to the measured data so that barrier heights
etc can be extracted.

    Full use has been made of colour and grey scales in order to
maximise the visual content of the information presented on the
display screen and all display modes are easily selected using a
combination of menus and softkeys.

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AUTOMATIC PROBER FOR THE DC CHARACTERISATION OF GALLIUM ARSENIDE
DEVICES

PART TWO :- THE DATA SORTING AND DISPLAY FACILITY

CONTENTS

AUTOMATIC PROBER FOR THE DC CHARACTERISATION OF
GALLIUM ARSENIDE DEVICES

PART TWO :-   THE DATA SORTING AND DISPLAY FACILITY

1)   INTRODUCTION

RSRE Memo No 4065 described the measurement aspects of the
DP2 prober system. This memo describes the data handling aspects
of the system and, where applicable, defines the device
parameters being analysed.

The initial version of the autoprober system used the same
computer to both control the measuring system and sort and
display the measured data. This system soon proved to be a major
bottleneck in wafer processing as the HP86 computer used was
relatively slow in sorting and displaying the data and a queue of
wafers waiting to be probed soon built up.   An additional demand
on the system was caused by the enthusiasm with which the
processing   teams adopted the wide range of   measurements
available. It was also realised during this period that computer
printers and plotters were not necessarily clean room compatible.
Owing to these factors it was decided to separate the two
functions of the probing system and construct a separate data
handling and display facility outside the clean area.   The
computer used for this facility was chosen to be better suited to
the data handling and display requirements. A separate suite of
software was written to take full advantage of the extra
sophistication and speed for which the need had become apparent.

The computer system on which this facility is based is
described in section two of this memo.   The various options
available for displaying the data are described in section three.
Section four of this memo describes the specific details of the
individual measurements and section five describes the software
used for data handling, parameter extraction and display. A full
software listing is given in a separate Appendix.

2)   HARDWARE DESCRIPTION

COMPUTER:- Hewlett Packard 9000 Series 300

Technical computer fitted with 3 Mbyte of random access
memory.   The primary operating system is BASIC version 4.0. The
display system is bit-mapped and a 12 inch colour monitor is
fitted.   A Hewlett Packard 9122D 3.5 inch disc drive is used for
program and data storage. Operator input is either by keyboard
or mouse.

PLOTTER:- Hewlett Packard 7475A 6 pen graphic plotter.

PRINTERS:- Hewlett Packard 2225A Thinkjet matrix printer, used for screen dumping.

Epson FX100, used for printed data output.

3) DISPLAY OPTIONS

i) GENERAL

In order to make full use of the data available it was decided that the general approach would be to attempt to combine facilities for obtaining an overall impression of device parameters with the ability to select and display data down to individual device level. A consequence of this approach is that a large amount of computer storage is required so that complete data files can be stored in RAM ready for immediate access. Storage is also required for parameters derived from the measured data. A strong emphasis was placed on the visual presentation of data with full colour and grey scale displays considered essential. As the system would be available for general use a menu driven system was designed with all commands entered using softkeys. The particular display options required for different data sets are automatically selected by the computer.

ii) HISTOGRAMS

The most straightforward way of indicating the range and distribution of a set of data is to display it in histogram form. The histogram program written for this system automatically scales the X axis from zero to the maximum value measured and selects a large box size to give an initial display of all the data gathered, figure (1). Options are then made available to reduce the box size and select alternative maximum and minimum values for the X and Y axes. Figure (2) shows a selected region of figure (1) and demonstrates the effect of reducing the box size and restricting the data range.

All histogram plots contain a data panel down the right hand side of the display. The parameters displayed in this data panel are defined below and are illustrated with an example based on a wafer containing a 10 x 10 array of FETs with the prober commanded to probe a 10 x 11 array.

a) BOXSIZE

The size of the class interval used to produce the histogram being displayed.

b)   COLUMNS

The number of devices in the X direction the prober was commanded to probe. In the example COLUMNS = 10.

c)   ROWS

The number of devices in the Y direction the prober was commanded to probe. In the example ROWS = 11.

d)   OFF WAFER

The number of times the prober edge detector indicated an off wafer condition during the probing run. In the example the eleventh row is assumed to be off the wafer and:-

OFF WAFER = 10.

e)   TOTAL PROBED

The actual number of device sites probed ie:-

(COLUMNS X ROWS) - OFF WAFER.

This parameter takes account of the fact that although the prober table movements are defined as a rectangular array most wafers are circular or semi-circular.

In the example OFFWAFER = 10 therefore:-

TOTAL PROBED = (10 x 11) - 10 = 100.

f)   NUMBER PLOTTED

The total number of data points occurring in the data range selected, ie the sum of the class frequencies of all the boxes displayed on the associated histogram plot. It should be noted that NUMBER PLOTTED will vary as the Xmax and Xmin values are altered.

If, in the example, we assume that Idsso is being plotted over the data range from 20 to 40 mA and that 10 devices have Idsso values between 20 and 40 mA, then:-

NUMBER PLOTTED = 10.

g)   OVERALL YIELD

During probing a number of tests are carried out on the data being obtained. Only those devices which

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pass all the relevant tests are classed as successful devices. The DEVICE YIELD is defined as "the total number of devices on the wafer which lie within all the default failure limits operating during probing".

$$\text{The OVERALL YIELD} = \frac{\text{DEVICE YIELD}}{\text{TOTAL PROBED}} \times 100\%$$

If, in the example, it is assumed that a total of 30 FETs, out of the 100 possible, passed all the probing tests then the DEVICE YIELD = 30 and:-

$$\text{OVERALL YIELD} = \frac{30}{100} \times 100\% = 30\%.$$

h)   DISPLAY YIELD

This relates to the particular device parameter being displayed and is defined as:-

$$\text{DISPLAY YIELD} = \frac{\text{NUMBER PLOTTED}}{\text{TOTAL PROBED}}$$

If, in the example, we assume that 15 FETs failed any one of the measurements preceeding the Idsso measurement and if we also assume that a further 25 FETs failed during the Idsso measurement then, at the conclusion of the Idsso measurement, a total of 40 FETs have failed (ie 15 + 25). Of the 100 devices possible on the example wafer 60 are therefore left at the conclusion of the Idsso measurement.

If the Idsso histogram is plotted for the complete data range then:-

$$\text{DISPLAY YIELD} = \frac{60}{100} \times 100\% = 60\%$$

If the data range of the histogram is altered to cover the range from 20 mA to 40 mA and if 10 FETs have Idsso values within this range then in this case:-

$$\text{DISPLAY YIELD} = \frac{10}{100} \times 100\% = 10\%$$

i)   MAXIMUM

The maximum value measured for the particular parameter being displayed.

j)   MINIMUM

The minimum value measured for the particular parameter being displayed.

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k)   **MEAN**

The arithmetic mean of all the data points within the data range selected.

ie: $\frac{\text{(The sum of the data points between x max and x min)}}{\text{NUMBER PLOTTED}}$

l)   **STANDARD DEVIATION**

The standard deviation of all the data points within the range selected.

Std. Dev. $= (\bar{x}^2 - (\bar{x})^2)^{\frac{1}{2}}$

iii)   **MAPS**

In order to fully assess any process, or combination of processes, it is necessary to examine the geographic distribution of the measured device parameters as well as the numeric distribution. Three types of map display are available, these show the geographic distribution of the numeric data, the geographic distribution of the failure modes of any failed devices and the geographic distribution of devices with a specified set of electrical parameters.

a)   **GREY SCALE MAP**

This facility enables the geographic distribution of the numeric data to be displayed. The wafer data is examined device by device and each device is allotted a grey scale intensity which is related to the measured value of the device parameter being investigated. The grey scale map is drawn with each device represented by a rectangle, the intensity of the rectangle corresponds to the magnitude of the parameter and the relative position of the rectangle on the screen corresponds to the original position of the device on the wafer. Owing to printer limitations only seven grey scales are available to cover the range from black to white so the data is always sorted into seven consecutive classes with each class size equal to one seventh of the data range. The initial grey scale map drawn when this mode of display is selected has a data range between the minimum and maximum measured values of the parameter being displayed, figure (3). Subsequent maps can be drawn with data ranges selected in the same fashion as in the histogram mode. Figure (4) and figure (5) show how the distribution of the data can be highlighted with judicious control of the data range.

An additional feature of the map drawing program is also illustrated in these figures. Because the device X and Y pitches on the wafer are not necessarily

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equal the resultant map display, drawn using the same X and Y scales, can be elliptical rather than circular. A facility exists to allow different X and Y scales to be used for drawing, this results in the more representative displays shown.

b)   FAILURE MAP

As described in RSRE Memo 4065 the probing program contains a number of built in pass/fail tests for all device parameters measured. All failures are identified with a specific token which is stored in the array containing the measured data. The failure map makes use of these tokens and draws a colour map of the wafer with specific colours associated with specific parameter failures. An example of a failure map is shown in figure (6).

c)   SELECTION MAP

A useful facility, when selecting devices for RF testing, is the ability to specify an envelope of device parameters and then identify where those devices which lie within this envelope are located on the wafer. Figure (7), Figure (8) and Figure (9) show selection maps of the same wafer of FETs in which Idsso ranges of 20 to 30 mA, 30 to 40 mA and 40 to 50 mA have been used as a single selection parameter. The selection program allows any number of parameters to be combined to form a "device specification" or "device template". In addition to the map display a printer output of the measured DC parameters of all devices selected can be obtained.

This facility can also be used to assess the device yield on a wafer using more realistic pass/fail criteria than the very broad ones used during device probing.

iv) SCATTER PLOTS

This option operates on FET data only and allows any two measured FET parameters to be plotted against each other. An example of a scatter plot is shown in figure (10). Facilities are available to plot the data on logarithmic scales and select the data ranges for the X and Y axis.

4) MEASUREMENT DETAILS

i) RESISTANCE

This measurement option is usually used to determine the resistivity of the various metals deposited to form ohmic or Schottky contacts or interconnect tracks. It should be noted that although a four probe measurement technique is used allowance must be made, when interpreting the results, for parasitic series resistances due to the difficulty of placing the probes reproducibly and exactly.

The display options available include histograms, grey scale maps, selection maps and failure maps.

ii) CAPACITANCE

All capacitance measurements are carried out in the parallel equivalent circuit mode and values of capacity and conductance obtained. It should be noted that a parasitic probe contact resistance is always present owing to the two probe measurement circuit used.

Display options available include histograms, grey scale maps, selection maps and failure maps.

iii) TRANSMISSION LINE OHMIC MEASUREMENTS

This measurement is carried out using the 4 probe configuration described in the RESISTANCE section. Definitions of the parameters obtained are given below:-

a) CONTACT RESISTANCE (OHM-MM)

The resistance between the metallisation and an imaginary plane at the edge of, and perpendicular to, the ohmic metallisation. The value obtained for this parameter, although subject to experimental error, is a true experimentally determined one. The value for contact resistance presented is normalised to ohm-mm.

b) SPECIFIC CONTACT RESISTANCE (OHM-CM^2)

The contact resistance of a unit area for current flow perpendicular to the contact. An assumption underlying the approach used to extract this parameter is that the sheet resistance of the semiconductor under the contact pad is the same as that in the gap between the contacts. Caution should be exercised when assessing the quality of ohmic contacts using this particular parameter

c) OHMS PER SQUARE (OHMS or OHMS per SQUARE)

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The sheet resistance of the conducting layer of
semiconductor between the ohmic contacts. The value
obtained for this parameter is a true experimentally
determined one.

A full treatment of the theory on which the
measurement technique is based is given in Ref (1). To
supplement the definitions given above a brief
description of the physical principles underlying the
technique used in the DP2 system is included in this
section.

The DP2 standard test structure consists of 5
ohmic contact pads fabricated on a mesa 100 microns
wide. The contact pads are separated by gaps of 5, 10,
15 and 20 microns. The semiconductor surrounding the
mesa is semi-insulating and the mesa itself is etched
in the same fashion as any device mesas on the wafer.
When a voltage is applied between two adjacent ohmic
contacts a current flows along one ohmic contact,
transfers to the semiconductor and flows across the gap
between the pads before transferring out of the
semiconductor into the second ohmic contact, fig (11).
The total resistance of the circuit described is
comprised of the resistance of the semiconductor in the
gap between the two ohmic contacts and two equal
contributions due to the contact resistance between the
ohmic contact pads and the semiconductor, ie:-

$$R_{measured} = R_{gap} + 2 \times (contact\ resistance) \qquad (1)$$

If the separation between the two pads is lg,
the width of the mesa is W and the sheet resistance of
the semiconductor in the gap is R_{SH} ohms per square
then:-

$$R_{gap} = R_{SH} \cdot lg/W$$

equation (1) therefore becomes

$$R_{measured} = R_{SH} \cdot \frac{lg}{W} + 2 \times (contact\ resistance) \qquad (2)$$

At each test site $R_{measured}$ can be obtained for
several values of lg, a straight line fitted to this
data will have the following properties:-

$$Slope = R_{SH}/w \qquad (3)$$

Intercept on $R_{measured}$ axis = 2 x (contact resistance) $\qquad$ (4)

The contact resistance and sheet resistance can
be obtained from equations (3) and (4). It is usual to
quote the contact resistance normalised for a 1mm wide
gap, i.e:- normalised contact resistance = (contact

resistance) x W ohm-mm.

In order to obtain a value for the specific contact resistance of the ohmic contact the area of the contact is required. Due to the complex manner in which the current progressively transfers from the ohmic contact into the semiconductor a parameter called the "transfer length", (lt), is defined which corresponds to the length, in the direction of the current flow, over which (1-1/e) of the current transfers from the contact pad to the semiconductor. This transfer length is measured from the edge of the gap. The effective contact area is therefore lt x W. In order to obtain a value for lt it is assumed that the sheet resistance of the semiconductor under the contact pads is the same as the sheet resistance in the gap between the contacts. Equation (2) then becomes:-

$$R_{measured} = R_{SH}.\frac{lg}{w} + 2 \times R_{SH}.\frac{lt}{w} \qquad (5)$$

A straight line plot of this data yields the same sheet resistance and contact resistance information as before but allows lt to be estimated from the intercept of the fitted line with the lg axis.

ie. when $R_{measured} = 0$

$$R_{SH}.\frac{lg}{w} = - 2 \times R_{SH}.\frac{lt}{w} \qquad (6)$$

Cancelling terms in equation (6) gives:-

Intercept on lg axis = -2 lt.

hence:- Specific Contact Resistance = (Contact Resistance) x lt x W ohm-cm^2

In addition to the general contact parameters described above the measured resistances for each gap can be displayed, fig (1) and fig (2). Histograms, grey scale maps and selection maps can be obtained for all parameters allowing the uniformity of alloying, metal deposition etc to be investigated.

In an attempt to eliminate the occasional inconsistent individual gap measurement the data for each test site is examined prior to map plotting. If the measured resistance for a particular gap is higher than the measured resistance for the next (larger) gap then the data set for that particular test site is classed as "invalid data". It should be noted that all measurements are included in the histogram plots for the individual gap resistances.

To allow the quality of the data to be assessed plots of the measured resistances vs gap length can be displayed for each test pattern site. The measured data and the best straight line fitted to the data are displayed as is the correlation coefficient for the fitted line.

The comments made in the section on RESISTANCE regarding parasitic series resistances due to the difficulty of placing probes exactly and reproducibly also apply here. Particular attention should be given to the series resistance due to the high resistivity of the various alloys used to form the contacts. The data analysis relies heavily on accurate values for the interpad gaps, to allow for the inevitable processing variations the default values of 5, 10, 15 and 20 microns can be replaced with accurately measured ones. The facility also exists to change the default mesa width of 100 microns.

iv) FIELD EFFECT TRANSISTORS

The FET parameters extracted are defined in figure (12). Histograms, maps and scatter plots can be obtained for all FET parameters.

Selection maps have proved to be of particular use when investigating FET data and the following abbreviated "device specification" forms a good basis for assessing the true overall yield on a wafer of 200 micron gate width FETs:-

	MIN	MAX
Rslope (Ohms)	5	40
Idsso (mA)	20	60
gm (mS)	15	maximum measured
Igate (microamps)	minimum measured	5

v) DETAILED FET CHARACTERISTICS

This facility is mainly used to provide experimental data to assist in establishing device models. Display options are limited to plots of the measured Vds vs Ids characteristics, figure (13), plots of Ids vs Vgs, figure (14), Gm vs Ids and Gm vs Vgs. For plots other than Vds vs Ids the data can be plotted at a selected value of Vds.

vi) DIODE FORWARD CHARACTERISTICS

The electrical parameters of a Schottky diode can be used to monitor "standard" processing and assess the practical effects of improved or alternative fabrication

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processes. This measurement option allows extraction of the ideality, barrier height and series resistance of Schottky diodes. A full mathematical treatment of the measurement can be found in Ref (1) and Ref (2) but as an aid to the user, an outline of the technique used in the DP2 system is given below:-

The simplified equation governing the behaviour of a Schottky diode is taken to be:-

$$I = Io \exp \frac{(qV)}{(nkT)} \qquad (1)$$

I is the forward diode current at forward voltage V
q is the electronic charge 1.602 E - 19 Coulombs
n is the ideality factor
k is Boltzmann's constant, 1.38 E - 23 J/K
T is the absolute temperature, 295K
Io is defined as:-

$$Io = Area\ of\ diode.\quad A*.T^2 \exp \frac{(V_B.q)}{(kT\quad)} \qquad (2)$$

where A* is the effective Richardson constant, 8.4 A/cm^2/K
VB is the barrier height in eV.

Taking logs of equation (1)

$$\log_e I = \frac{qV}{nkT} + \log_e Io \qquad (3)$$

A plot of $\log_e$ I vs V will give a straight line with

$$slope = \frac{q}{nkT} \qquad (4)$$

$$Intercept = \log_e Io \qquad (5)$$

The ideality and barrier height are obtained using equations (4), (5) and (2).

The straight line fitting to the measured data can either be carried out automatically by the computer or a fit between two selected current levels can be requested. The automatic fitting routine examines each decade of current and performs a least squares fit on the 10 data points within that decade. A measure of the "goodness" of the fit for each decade is calculated by summing the squares of the deviations in each case. The best straight line for the complete set of data is then assumed to be that line which has the best fit over one decade of the current range. The manual curve fitting routine simply performs a least squares fit to the data between the two values of current selected. The correlation coefficient displayed in the data panel

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refers to the best straight line fit over one decade of the linear region of the diode characteristics in the auto fitting mode. The correlation coefficient quoted for manual fitting is for the range selected.

Having selected the best straight line the program then determines the difference, at the maximum forward current, between the actual forward voltage measured and the forward voltage predicted by the fitted line. This voltage difference is assumed to be due to the voltage drop across the series resistance of the diode. Knowing the associated current the series resistance of the diode can be calculated. A plot of the combined diode fit plus series resistance is then drawn for comparison with the measured data, fig (15). It should be noted that in order to obtain the maximum voltage drop across the series resistance the diode forward current should be maximised. Excessive currents through small area Schottky diodes can however cause permanent damage so a compromise value of forward current may have to be used.

The diode I/V measurement can be performed using the auto step facility, histograms and maps of the diode parameters can be displayed in the usual manner.

vii) *C/V PROFILING*

This program is usually used to analyse data obtained from measurements on a standard FATFET. Unless told otherwise the computer assumes the size of the Schottky contact is that of a FATFET, ie 100 x 150 microns. Typical zero bias capacities of FATFETs are in the range 20 pF to 40 pF. C/V measurements have been carried out on real devices with zero bias capacities of 2 to 4 pF, a small number of measurements on smaller capacity devices have successfully been carried out.

The carrier concentration values are extracted from the C/V data using the standard approach as described in Ref (3), it should be noted that no corrections are applied for fringing capacitance or series resistance due to the planar geometry of the FATFET structure. Owing to these series resistance effects doping profiles are likely to be inaccurate at doping levels below 10^{15} cm^{-3}.

C/V measurements can be performed across a wafer using the autostep facility, grey scale maps of the carrier concentration near the surface can be produced to indicate variations across the wafer. It should be remembered that the data obtained will contain variations due to non-uniformity of processing in addition to any non-uniformity present in the starting material.

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Individual plots of C vs V and Nd vs depth can be obtained by using the mouse to pick the individual device field off a map of all the device fields measured. A display option is available which will allow all the profiles obtained from a wafer to be overlaid in the same display, figure (16). This type of display can sometimes be confusing as the program assumes that any etching has been uniform across the wafer and that all test patterns have been fabricated on the same level. If an absolute depth scale is required a facility is available to add a known etch step to the data.

5) SOFTWARE DESCRIPTION

i) GENERAL

All the programs are written in BASIC Version 4.0 and are initially loaded into memory on power up from a program called (Autost). User interaction with the software is via the computer keyboard and a mouse.

On program start a menu is displayed defining eight softkeys, only two of these softkeys, ie softkey f7 and f8, are active initially, see fig (17). Softkey f7 is labelled ENTER DATA and is used to load the appropriate data file to be analysed. Before the data files can be analysed by the program they must first be converted from the HP 86B disc storage format to the SERIES 300 disc storage format. Soft key f8 is used to select the data conversion program. Once converted the data is stored, in SERIES 300 Format, on a working disc. The HP86 disc is kept as an archive copy.

Assuming all the data files have been converted to the Series 300 computer format then selection of softkey f7 presents a display of the contents of the data disc directory file. Each file name is displayed along with its associated description and probing date. To select a data file the operator is instructed to use the mouse which moves a white band up or down the screen. File selection is made by placing the white band over the file name and description and pressing either of the MOUSE KEYS. Dependant upon the file type selected the relevant subroutine or subprogram is called. These are as follows:-

Data Type 'F" Subroutine [Enterfetdata], line 729.
Date Type 'O' Subroutine [Enterohmicdata], line 744.
Data Type 'C' Subroutine [Entercapdata], line 778.
Data Type 'S' Subroutine [Enternewohmic], line 765.
Data Type 'P' line Cvselected,176 Subprogram [Cvplot]
Data Type 'V' line Viselected,182 Subprogram [Viplot]
Data Type 'I' line Idealitysel,188 Subprogram [Ideal]
Data Type 'R' line Transelected,194 Subprogram [Transline]

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Should any error occur when a data file is being loaded the program goes to [Initialstart] with a Boolean variable called 'Menucontrol' set 'False'. If the data file is read successfully variable 'Menucontrol' is set 'True'. If 'Menucontrol' is 'False' then the menu only allows selection of the two options selected by softkeys f7) & f8) ie, enter new data or convert data. If 'Menucontrol' is 'True' ie, a data file has been successfully loaded into memory, the following additional softkeys are active from the menu:-

        f1) HISTOGRAM PLOTTING
        f3) MAPPING
        f4) SELECTION MAPPING
        f5) SCATTER PLOTTING
        f6) FAILURE MAP
        See fig (18)

A detailed description of each of these options is given in the following sections.

ii) HISTOGRAM PLOTTING

On selection of the Histogram option the program goes to Histselect, line 200. A subroutine called [Paramchange] is called which allows selection of the parameters for which the Histogram is to be plotted. For a FET data file the parameters are RSLOPE, IDSSO, GD, VKNEE, GM, IGATE, IDSS4, and VPINCH. A capacitance file has two selectable parameters, CAPACITANCE and CONDUCTANCE. Selection of a parameter is made by softkey in subprogram [Selectparam], line 1909, which is called up from subroutine [Paramchange]. When a parameter has been selected a variable called 'Paramcase' is given a fixed value to identify the selection. In subroutine [Paramchange] the value of 'Paramcase' determines which data is placed in a variable array called 'Fetval'. The maximum and minimum values are stored in variables 'Devmax' and 'Devmin'. The string variable 'Param$' stores the data for plot titles. The array 'Fetval' is a common array available to all subprograms.

After selecting a parameter the program enters the subprogram [Histogram], line 1453. A data array called 'Value' is allocated and a default boxsize is given to variable 'Boxsize' according to the value in variable 'Hmax', program lines 1469 to 1474. The measured parameter values in array 'Fetval' are extracted, sorted into numerical order and then stored in the sorted form in an array called 'Value'. The histogram box filling routine takes the form of a program loop between lines 1496 and 1506. On entry into this loop a pass window is defined of size minimum value to minimum value plus 'Boxsize'. This window is compared against the sorted array 'Value' to determine the number of device measurements that occur within the window. The number of devices that occur in the

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window variable 'Numbox' are then stored in an array called 'Box'. In the loop the upper and lower boundaries of the window are incremented by 'Boxsize' and the process is repeated until the window exceeds the maximum measured value or the number of devices in the array 'Box' equals the total number of devices measured. The array 'Box' is then plotted graphically on the colour monitor screen as a histogram. The default scale for the 'X' axis is minimum = 0, maximum = variable 'Devmax'. The scale for the 'Y' axis is determined by the highest value of the variable 'Numbox'.

A typical histogram display is shown in figure (1).

After the histogram has been plotted five softkeys are allocated to a Histogram menu from which the user can select the following options:-

> f1) RETURN TO MAIN MENU
> f2) UNUSED
> f3) CHANGE BOXSIZE i.e. 10, 5, 1, .5, .1, OR .01
> f4) EXPAND X OR Y AXIS
> f7) PLOTTER COPY
> f8) PRINTER COPY

Selection of softkey f1) aborts the histogram plotting routine and returns the program back to the main menu. Softkey f3) allows the boxsize to be changed. Once the boxsize has been changed the box filling routine described earlier is repeated with the new value for "Boxsize", the results are displayed on the screen as before. Softkey f4) allows selected regions of the 'X' and 'Y' axes to be plotted. Selection of softkey f4) calls subprogram [Enter maxmin], line 3032. This subprogram allows new 'X' and 'Y' maximum and minimum values to be entered. Exit from the subprogram is by softkey f1) which is allowed only if the maximum values entered are greater than the minimum values entered. On exit from the subprogram the histogram is automatically redrawn with the new axes.

Selecting softkey f7) produces a hard-copy plot of the screen display drawn on a six colour pen plotter. Softkey 'f8' performs a screen dump to an inkjet printer which is monochrome only.

iii) GREY SCALE MAP

The map is plotted to a default scale held by the variables 'Devmax' and 'Devmin' of the selected parameter. Seven intensities or seven shades of grey are used to represent the data. The window for each intensity or shade of grey is calculated by subtracting the minimum value 'Devmin' from the maximum value 'Devmax' and dividing the result by seven. Seven windows are therefore created into which the data can be slotted, the values being held in variable array 'Inc'. The map is plotted within a double

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loop in the program.   The number of times the first loop is
repeated is determined by the number of device columns
(variable 'Xcol').   The number of times the second loop,
which is inside the first loop, is repeated is determined by
the number of device rows (variable 'Yrow').   Each increment
of the loop corresponds to the measured device data and
position.   Program lines 1108 to 1176 show the comparison of
the measured device data to the window variable 'Inc'.   The
result of each comparison is a shade of grey value held in
variables 'Areapen' and 'Areaint'.   A rectangle is then
plotted on the colour monitor screen and shaded with the
value held in variable 'Areapen'.   Figures 3, 4 and 5 show
completed maps with offwafer devices being represented by a
red rectangle with a diagonal slash.   Once the map has been
completed a subprogram called [Mapscalenum], line 2787, is
called to draw in the device numbers.   On completion of the
map drawing eight softkeys are defined as follows:-

                f1) :- RETURN TO MAIN MENU
                f2) :- CIRCULAR MAP
                f3) :- SAMPLE MAP
                f4) :- CHANGE MAX-MIN
                f6) :- PLOTTER SHADING
                f7) :- PLOTTER NUMBERS
                f8) :- PRINTER COPY

     Softkey f1) performs the same functions as in the
histogram routine.   Selection of softkey f2) re-plots the
wafer map using anisotropic scaling as opposed to the
default isotropic scaling.   The result of this is to produce
a rounded map from an elliptical map.   Subprogram [Mapint].
line 3192 is called to set up the scaling as determined by
Boolean variable 'Circ'.

     Selecting softkey f3) re-plots the wafer map using
isotropic scaling. Selection of softkey f4) calls subprogram
[Maxmin], line 1973. This subprogram allows the maximum and
minimum values of the parameter being mapped to be altered.
If the maximum value entered is greater than the minimum
value entered the wafer map is automatically re-drawn.   If
the maximum value entered is less than the minimum value
then an error is reported and the program will not continue
until the maximum and minimum values are entered correctly.

     Selection of softkey f6) uses the system plotter to
plot the wafer map with shaded rectangles to represent the
grey scale intensities.   Subprogram [Plotter-shade], line
3275, is called to perform this task.

     Selection of softkey f7) draws the plot on the system
plotter with numbers instead of intensities to represent the
parameter values.   The numbers are 1, 2, 3, 4, 5, 6 and 7,
with 7 corresponding to white.

     Selection of softkey f8) dumps the screen image to the

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line printer. It should be noted that the printer image is the inverse of the screen image i.e. white on the screen is black on the printer. Selection of softkey f8) turns off the colour mode used to draw the wafer map and re-draws the wafer map on the screen with a seven level intensity scale. The reason for drawing with intensities is to allow the screen to be dumped to the system printer. With the existing system printers it is not possible to dump full grey scale or colour images but a future option may be to connect the computer to a colour video printer.

The grey scale is inverted on the screen so that the screen dumped image corresponds to the original grey scale wafer map on the screen, the original screen display is automatically recalled on completion of the screen dump.

iv) SELECTION MAPS

Selecting softkey f4) in the main menu calls up a selection mapping routine. This routine allows the operator to specify a particular combination of device parameters and form a device "data sheet". Each device is compared against the "data sheet" and the locations of those which fit are then plotted in the form of a wafer map. The subroutine [Limitmapf], line 2018, is used to carry out this selection process.   At present only data files type 'F' (FETs), 'O' (OHMICS), and 'C' (Capacitors) can be selection mapped.

Subroutine [Limitmapf] displays a table containing the "data sheet" parameters alongside the measured maximum and minimum values of each parameter. The parameter to be changed is selected using the mouse and the required maximum and minimum values for that parameter are entered using the keyboard. The selected maximum and minimum limits are stored in a variable array called 'Lim2'. Subroutine [Passvalues], line 906, uses the array 'Lim2' to determine which devices pass the selected limits. The results are stored in an array called 'Passval'. A device that fails the selected limits is given the value -20 whilst a device that passes is given a value of 1.

Once the subroutine [Passvalues] has been completed subprogram [Mapping_limits], line 2697, is called. This subprogram plots the array 'Passval' in the form of a wafer map. Once the map has been plotted eight softkeys are allocated from which the user can select the following options:-

            f1) :- RETURN TO MAIN MENU
            f2) :- CHANGE LIMITS
            f3) :- RESET LIMITS
            f4) :- PRINTER COPY OF DEVICES PASSED
            f5) :- SELECT DEVICE
            f7) :- PLOTTER COPY
            f8) :- PRINTER COPY

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Selection of softkey f2) permits the maximum and
minimum pass/fail limits to be changed again if required.
The pass/fail limits can be reset to the default maximum and
minimum values by selection of softkey f3).

A printer copy of the measured data for all the devices
which fit the "data sheet" can be obtained by selecting
softkey f4). Selection of softkey f5) stores the screen map
in an array called 'Gscreen'. A routine is then entered
which allows selection of an individual device from the
plotted map. Selection of a device is made via the mouse
and subprogram [Pickdev], line 2634. Only a device that has
passed can be chosen. Once a device has been selected the
following options are available:-

<div style="text-align:center">

f1) :- RETURN TO MENU
f4) :- PRINT DEVICE DATA
f5) :- IDS PLOT
f6) :- SELECT DEVICE
f8) :- PRINTER COPY

</div>

Softkey f4) provides a printout of the measured data
for the device selected. Selection of softkey f5) is only
possible if the data is of type 'F' ie, FET measurement
data. If softkey f5) is selected with a FET data file then
a simplified characteristic curve of the device is plotted
on the screen. An example of this simplified curve is shown
in figure (19). A printer copy of the screen picture can be
obtained by selecting softkey f8). Selection of softkey f6)
redraws the memorised selection wafer map from array
'Gscreen' and allows another device to be selected. Softkey
f7) provides a plotter copy of the screen picture.

v)   SCATTER PLOTTING

Data files containing at least two measured parameters
can be scatter plotted. When the scatter mode is selected
the operator is instructed to select the 'X'axis parameter.
This is achieved in line 501 where subroutine [Paramchange]
is called. The operation of subroutine [Paramchange] is
described in the section on Histogram plotting. After
selecting the 'X' axis parameter the array called 'Passval'
is used to hold the measured data. The program then asks
the operator to select the 'Y' axis parameter. The 'Y' axis
measured data is retained in the array 'Fetval'.

After choosing the parameter axes subprogram
[Scattermap], line 1732, is called. This subprogram scales
and sets up the axes and then plots the selected parameters
against each other. On completion of the plot the following
scatter mode menu is active via the softkeys:-

<div style="text-align:center">18</div>

```
f1)  :- RETURN TO MAIN MENU
f2)  :- RESET RE-PLOT
f3)  :- LOG X/Y AXES
f4)  :- EXPAND X/Y AXES
f5)  :- CHANGE PARAMETER
f6)  :- OVERDRAWMODE
f8)  :- PRINTER COPY
```

Selection of softkey f1) aborts the scatter plotting mode and returns the program to the main menu. Selection of softkey f3) redraws the scatter plot with logarithmic axes. Both axes at present are drawn with logarithmic scales. Selection of softkey f4) calls subprogram [Entermaxmin] to change the 'X' or 'Y' axis scaling. Figure (10) is a photo of the screen display of a typical scatter plot. Selection of softkey f6) allows the operator to enter a different data file and overlay the data stored on screen with the new data. Selection of softkey f2) cancels the overdrawmode and resets the screen to a scatter plot of the parameters selected for the last data file entered.

vi) **FAILURE MAPS**

This option plots a map of the devices which were classed as failed devices during the original probing run, the map also identifies the nature of the failure. If the devices are FETs then the array 'Fetval' is automatically filled with the values of the 'Vpinch' array. As described in part 1 of this memo failures are identified by suitable tokens which are stored in the 'Vpinch' array. Subprogram [Failuremap], line 2163, plots the failure map. Coloured rectangles are used to distinguish the different failures. Figure (6) is a photo of the screen display. If a printer copy is requested then subprogram [Printfailmap], line 2877, is called and instead of coloured squares to identify failures, characters are used. Once a failure map has been plotted the following softkeys are redefined for the failure map mode:-

```
f1)  :- RETURN TO MAIN MENU
f2)  :- CIRCULAR MAP
f3)  :- SAMPLE MAP
f6)  :- PLOTTER COLOUR
f7)  :- PLOTTER LETTERS
f8)  :- PRINTER COPY
```

Selection of softkey f6) calls subprogram [Color_failmap], line 3399. This subprogram produces a failure map on the system plotter using coloured rectangles and shading to distinguish between different failures. Figure (21) shows an example of the coloured plotter failure map. Selection of softkey f7) produces an alternative plotter output using the same character set as the printer. A typical plotter display is shown in figure (20).

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vii) C/V MEASUREMENTS

If a data file type 'P' (C/V measurement) has been
selected subprogram [Cvplot] is automatically loaded and
executed. This subprogram starts by reading the disc data
file and placing the measured data into a variable array
called 'Cv'. A subroutine called [Cvmap], line 300, is then
called which plots a wafer map of the devices measured.
Devices with valid measurement data are distinguished by
being plotted with blue rectangles. The following options
are available when the wafer map has been plotted:-

                 f1) :- RETURN TO MAIN MENU
                 f2) :- Nd MAP
                 f3) :- CHANGE AREA
                 f4) :- Cv DATA MAP
                 f5) :- SELECT DEVICE
                 f8) :- PRINTER COPY

Selection of softkey f1) aborts the CV plotting routine
and returns the program to the main menu. Selection of
softkey f2) plots a grey scale Nd map using subprogram
[Mapsub] as described under Grey Scale mapping. The Nd
values displayed are calculated using the zero bias data
only. The map scale is derived by subtracting the minimum Nd
value from the maximum Nd value and dividing the result by
7. The default area, variable 'Area' used in the CV
calculations [Calcv], line 509, is 1.5 E-4 cm^2. Selection
of softkey f3) allows this area to be changed. Selecting
softkey f5) calls subprogram [Pickdev] which utilises the
mouse to select a specific device. Only devices with valid
data are allowed to be selected by the program.

Once a device has been selected, two softkeys are
redefined as follows:-

                 f4) :- Nd Profile
                 f5) :- Cap/Volt Plot

Selection of softkey f4) calls subroutine [Calcv], line
509 which calculates the Nd data and stores the results in
an array called 'Nd' and an array called 'Depth'. Subroutine
[Cvdraw], line 432 is then called and 'Nd/cc' is plotted
against 'Depth'. On completion of the 'Nd/cc' plot a
submenu [Submenul], line 108, is available to select any of
the following options.

                 f1) :- CV Menu
                 f3) :- X-Y Axis Expand
                 f4) :- Add Etch Step
                 f5) :- Overlay Allplots
                 f8) :- Printer Copy

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Selection of softkey f1) returns the program to the original CV Menu options, line 44. Softkey f3) uses Subprogram [Entermaxmin] to allow selected regions of the data to be plotted. Softkey f4) allows the etch step variable 'Etstep' to be changed. The default value for the etch step is 0. Softkey f5) allows all the valid device data to be overlayed on one plot. Softkey f8) provides a printer copy of the screen picture.

Selecting the Cap/Volt Plot option using softkey f5), plots the measured capacitance against the measured voltage of a selected device. Subroutine [Capvoltplot], line 375 is used to plot the capacitance/voltage data with the selected device number stored in variable 'Devnum'. On completion of the plot the softkeys are redefined as follows [Submenu2], line 197.

        f1) :- CV Menu
        f3) :- X-Y Axis Expand
        f5) :- Overlay Allplots
        f8) :- Printer Copy

These options perform the same functions as those described under [Submenu 1].

    viii) DETAILED FET V/I

When a data file type 'V' (FET voltage - current characteristic) has been selected the program automatically loads and executes subprogram [Viplot]. The subprogram starts by entering all the measured data from the type 'V' disc data file into an array called 'Reading'. The measured voltage and current values are then extracted from the array 'Reading' and placed in arrays 'Vds' for voltage values and 'Ids' for the current values. The softkeys are then defined with the following options:-

        f1) :- RETURN TO MENU
        f2) :- IDS/VDS PLOT
        f3) :- GM/VGS PLOT
        f4) :- IDS/VGS PLOT
        f5) :- GM/IDS PLOT
        f8) :- PRINTER COPY

Selection of softkey f1) aborts subprogram [Viplot] and returns the program to the main menu.

Softkey f2) IDS/VDS PLOT:- This calls subroutine [Vidraw], line 282, to plot the measured drain-source voltage against the drain- source current.

Softkey f3) GM/VGS PLOT:- Selection of this option first requires a drain-source voltage to be selected. Subroutine [Selectvds], line 101, allows selection of one of the following voltages 1.5 V, 2 V, 2.5 V, 3 V, 3.5 V, 4 V,

4.5 V and 5 V. The selected voltage is stored in variable 'Voltds'. Having selected a voltage, subroutine [Gmplot], line 181, is then called. The 'Gm' is calculated by subtracting two consecutive values from the array 'Ids' and dividing the result by the measurement voltage step, variable 'Vstep'. This is repeated for all the records and the results stored in the array called 'Gmp'. The subroutine [Gmplot] then plots the Gm values from the array 'Gmp' against the gate voltage. It should be noted that the gate voltages are not directly measured during probing and the variable 'Vstep' contains the increments called up by the probing computer.

Softkey f4) IDS/VGS PLOT:- Selection of this option first requires the operator to select a drain-source voltage as previously described. Subroutine [Vgplot], line 139, is then called to plot the drain- source current against the gate-source voltage.

Softkey f5) GM/IDS PLOT:- Selection of this option first requires the operator to select a drain-source voltage as previously described. The subroutine [Gidsplot], line 232, is then called to plot the Gm against the drain-source current. The Gm values are calculated as described under "Gm/Vgs" plot.

ix) DIODE FORWARD I/V

When a data file type 'I' has been selected the program automatically loads and executes subprogram [Ideal]. The subprogram starts by entering all the measured data from the type 'I' disc data file into an array called 'Id'. Each element of the array contains the measured I/V data for one diode. Subroutine [Idmap], line 452 is then called to display a wafer map on the screen. Devices with valid measurement data are distinguished by being plotted with blue rectangles. The following options are available upon completion of the wafer map:-

f1) :- RETURN TO MAIN MENU
f3) :- HISTOGRAMS
f4) :- MAPS
f5) :- SELECT DEVICE
f8) :- PRINTER COPY

Selection of softkey f1) aborts the subprogram and returns the program to the main menu. Selection of softkey f3) and softkey f4) call the subprogram [Histogram] and grey mapping subprogram [Mapsub]. Before either histograms or grey scale maps can be produced the subroutine [Fillarray] is used to calculate the Ideality factor, Barrier height and Diode series resistance for each device measured. [Fillarray], line 258, uses the automatic line fitting routine [Autocurve], line 169, to determine the slope and intercept of the linear portion of the diode characteristic for each

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individual device measured.   In order to determine the best
straight line fit to the measured device data [Autocurve]
splits the data into consecutive groups of ten readings.
The   least   squares program functions, [Lsq1] and [Lsq2] are
used to determine the intercept, slope and deviation of each
of these groups of readings.   The best straight line fit to
the linear region of the diode characteristic is assumed to
be the line fitted to the group with the smallest deviation.
The Barrier Height and Ideality are obtained using the
program   functions [Ideal_ity] and [Barrier_hgt].   The
voltage difference, at the maximum forward current, between
the value predicted by this fitted line and the actual value
measured is divided by the maximum forward current to give
the diode series resistance.   When the curve fitting and
parameter calculation for each of the devices measured is
complete a Boolean variable 'Devdata' is set True, this then
enables the Histogram and Mapping subprograms.   Histograms
and Maps of Ideality Factor, Barrier Height and Diode
Resistance can be produced.

     Selection of softkey f5) labelled 'Select Device' calls
subprogram [Pickdev] which utilises the mouse to select a
specific device.   Providing the device selected contains
valid data then the program calls subroutine [Plotideal],
line 327.   This subroutine plots the device current/voltage
characteristic on the screen, see fig (15). On completion of
the plot the following options are available:-

                    f1) :- I/V MENU
                    f3) :- AUTO CURVEFIT
                    f4) :- MANUAL CURVEFIT
                    f5) :- CHANGE AREA
                    f6) :- SELECT DEVICE
                    f7) :- PLOTTER COPY
                    f8) :- PRINTER COPY

     Selection of softkey f1) returns the subprogram to the
initial set of options previously described. Selecting
softkey f3) calls [Autocurve] which carries out the curve
fitting and parameter calculations described earlier in this
section and obtains values of the Barrier Height, Ideality
and Diode Resistance for the device.   A plot of the fitted
diode equation is then drawn superimposed on the measured
data and the Barrier Height, Ideality, Diode Resistance,
correlation coefficient for the linear region and fitting
coefficient for the complete characteristic are displayed in
the data panel.   The fitting coefficient displayed is the
sum of the absolute values of the differences between the
measured and fitted voltages.

     Selecting softkey f4) allows the operator to define the
region over which the straight line fitting is to be carried
out. The program performs a least squares straight line fit
to all the data points within the selected region.   The
diode parameters and fitting coefficients are displayed in

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the data panel as before.

x)   TRANSMISSION LINE OHMIC MEASUREMENTS

     When a data file type 'R' has been selected the program
automatically loads and executes subprogram [Transline].
The subprogram starts by entering all the measured data into
four array's called 'Arry20',   'Arry15',   'Arry10' and
'Arry5'. Subroutine [Caltrans], line 422, is then called to
calculate   the   Contact   Resistance,   Specific   Contact
Resistance and Ohms Per Square values for each set of valid
readings. Subroutine [Caltrans] performs a least squares fit
on the data as shown by program lines 434, 435. These values
are stored in arrays called 'Conres', 'Spcon' and 'Ohmsq'.
A subroutine called [Devmap], line 346 is then entered to
display a wafer map, on the screen, of devices with valid
data. Devices with valid measurement data are distinguished
by being plotted with blue rectangles.   The following
options are available upon completion of the wafer map.

               f1):- RETURN TO MENU
               f2):- CHANGE GAP SIZE
               f3):- HISTOGRAMS
               f4):- MAPS
               f5):- SELECT DEVICE
               f6):- DEVICE OVERLAY
               f8):- PRINTER COPY

     Selection of softkey f2) allows the default gap sizes
of 20 microns, 15 microns, 10 microns, 5 microns and the
default width of 100 microns to be changed in variables
'G20', 'G15', 'G10', 'G5' and 'Wide'. Selection of softkey
f3) calls subprogram [Histogram].   Selection of softkey f4)
calls subprogram [Mapsub].   Both of these subprograms have
been described previously in this memo. Histograms and Grey
Scale maps of the following parameters can be plotted: 20
microns,   15   microns,   10 microns,   and 5 microns gap
resistances,   the Contact Resistance,   Specific Contact
Resistance and Ohms per Square of the semiconductor between
the ohmic pads.

     Selection of softkey f5) calls subprogram [Pickdev]
which utilises the mouse to select a specific device from
the wafer map. Upon selection of a device subroutine
[Plottrans], line 198 is entered. This subroutine plots the
measured four gap ohmic readings together with the best
straight line fit to the data,   see figure (22).   A
correlation coefficient is calculated and displayed on the
plot.

     Selection   of   softkey   f6)   uses   subroutine
[Plottransall], line 250. This subroutine provides a screen
plot of all the valid device gap resistances together with
the best straight line fits all on one plot.   Figure (23)
shows an example of the overlayed screen plot.   Subroutine

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[Plattransall] also initialises array 'Passval' with all the calculated correlation coefficients. The array can be analysed in the Histogram and Grey scale mapping subprograms. The Boolean variable 'Correlation' is used to enable the 'Passval' array.

xi) DATA CONVERSION

The program that converts disc data files from the HP86 computer to the Series 300 computer is called [Convertdat]. This is a complete program which is loaded automatically from the display program when selected. The program starts by first reading the disc data file called [Directory] and converting it to the Series 300 format. Subprogram [Datamenu], line 640, uses the directory to display the disc data file information on the screen. Selection of a data file is made by moving a white band over the file name via the mouse. On selection of a data file the following options are available:-

> f1):- CONTINUE & CONVERT
> f7):- RE-SELECT
> f8):- RE-START

On selecting softkey f1) various error checking routines ensure valid data discs, valid directories and no duplicate file names exist. The actual conversion subprogram is called [Conversion], line 718. Default data file record lengths are given to variable 'Reclength' as described in part 1 of this memo. The subprogram initially converts the first two numbers of the data file i.e. number of columns 'Xcol' and number of rows 'Yrow'. From these variables the total number of numbers to be converted is calculated. Subroutine [Convertnum], line 805, actually converts the numbers. On completion of the number conversion the data is stored on a Series 300 data disc with the corresponding directory information updated. The following options are then available:-

> f1):- SELECT & REPEAT
> f2):- CHANGE 86 DATA DISC
> f5):- READ 300 DIRECTORY
> f6):- DELETE FILE
> f8):- ANALYSE DATA

Selecting softkey f8) aborts the conversion program and automatically re-loads the display program [Displaydat].

6) CONCLUSIONS

The decision to separate the two functions of the auto prober system has proved sound and has effectively removed the bottleneck at the measurement stages of wafer processing. The sophisticated graphics available have proved ideal for displaying data and the speed of the HP300 computer has allowed a useful

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interactive facility to be realised. The technique of accessing the display options by selection from a menu made very stringent demands on the structure of the software but the resulting facility has proved effective and popular as well as being easy to use. At the present time the hard copy printouts of screen maps do not reflect the quality and impact of the actual screen displays and this aspect of the facility deserves further investigation.

The system described in these two memos has been in regular use for the past eighteen months and has proved to be an invaluable tool in the device and device technology program of the division. The large increase in the speed at which devices are measured has enabled full device data to be gathered on large wafers allowing fine detail as well as general trends to be investigated. An additional benefit of the system has been the increased precision of the data compared to that previously obtained using a manual curve tracer. In addition to the speed and precision benefits of the measurement system the computer data handling has allowed full advantage to be taken of the large volume of high quality data available. The complete system has now become an essential part of the DP2 processing facilities.

7)   ACKNOWLEDGEMENTS

Although all the software described in these memos was written specifically for this autoprobing system three of the routines used are based on sections of programs which already existed within DP2 Division. We would like to acknowledge these contributions from the following individuals: J Birbeck, D Lee and J Smith for the routine used to extract Nd and depth in the C/V profiling programs, K Hilton and G Pryce for the basis of the curve fitting routine used in the diode I/V measurements and J Gaskell for supplying the routine originally used to convert the data from HP86 format to HP300 format. Finally we would like to acknowledge the helpful discussions with J Woodward and the co-operation of the rest of the processing section in carrying out the field testing of the system.
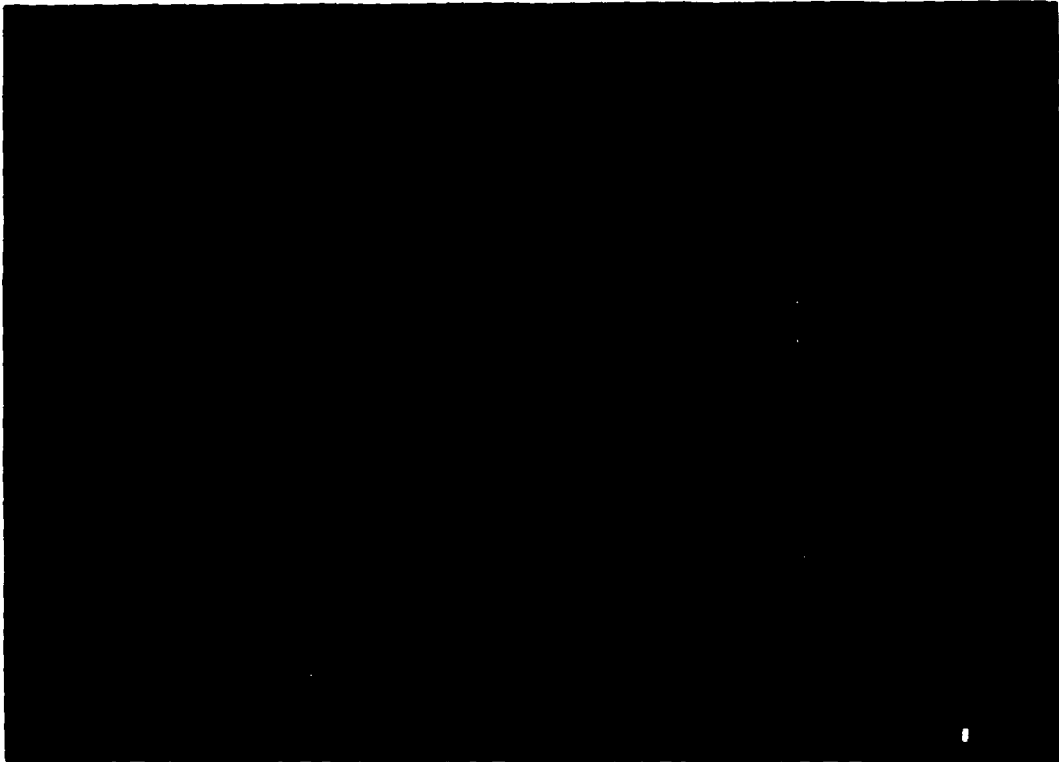
8)   REFERENCES

Ref (1)   R E Williams, "Gallium Arsenide Processing
           Techniques", publ. by Artech House, inc. 1984.

Ref (2)   V L Rideout, Thin Solid Films, $\underline{48}$ (1978) 261-291.

Ref (3)   S M Sze, "Physics of Semiconductor Devices", 2nd
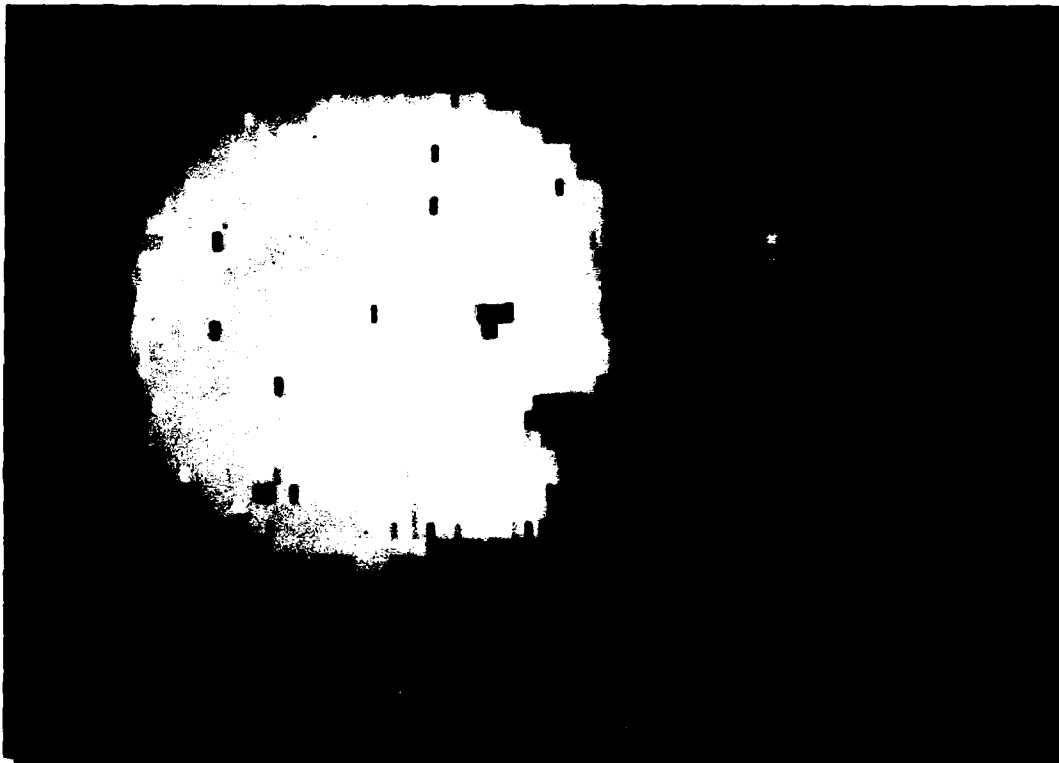   Ed. publ. by Wiley-Interscience, 1981.
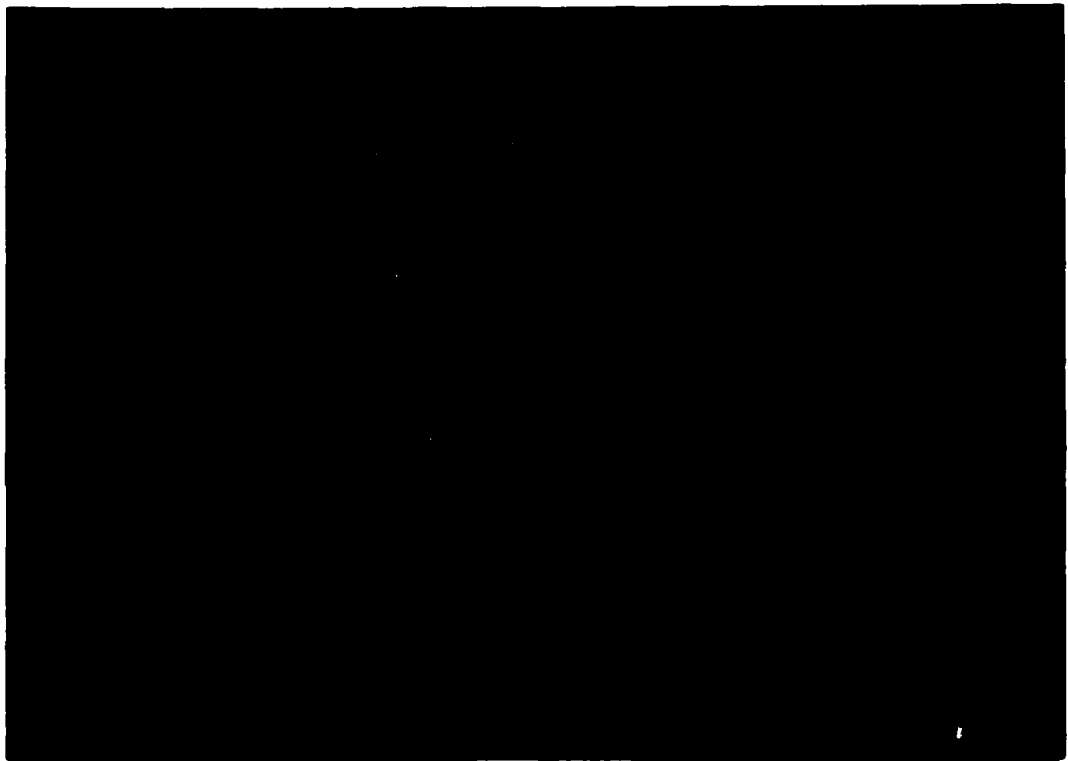
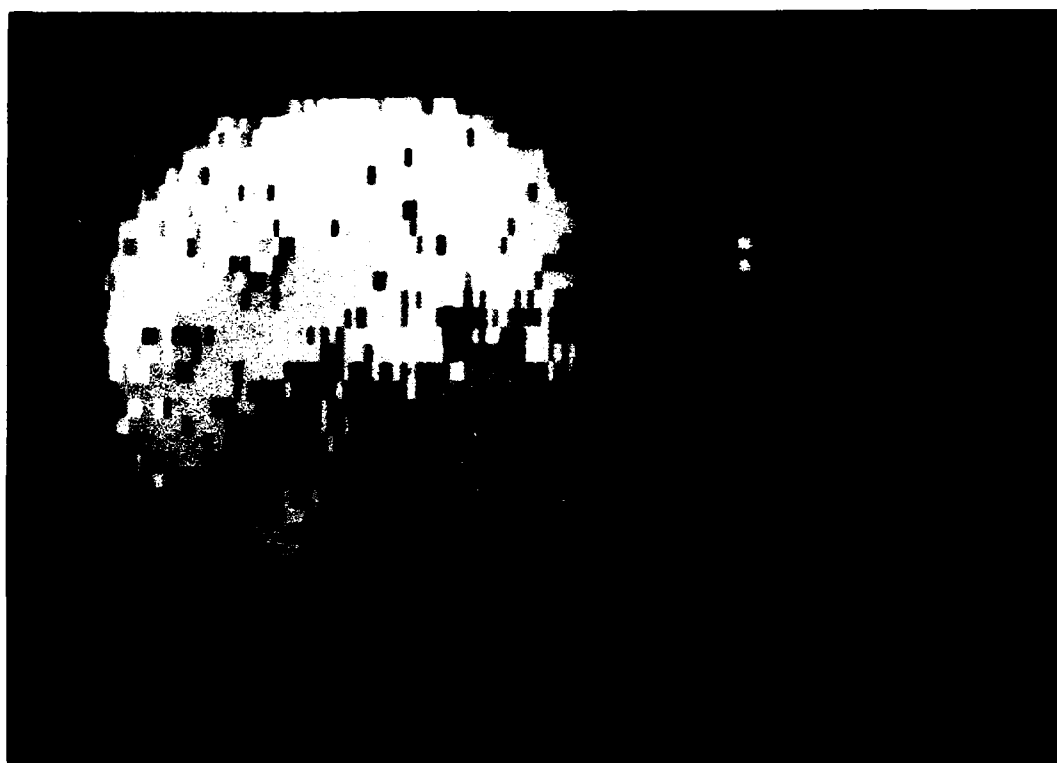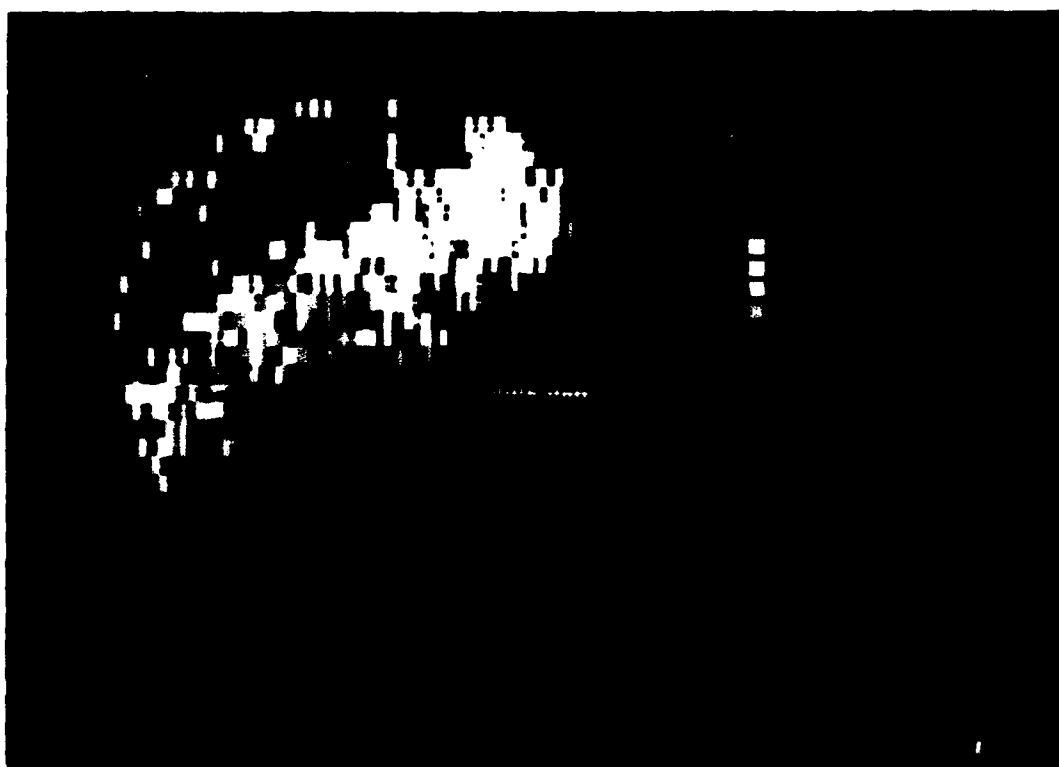**FIGURE 1 TYPICAL HISTOGRAM PLOT OVER FULL DATA RANGE**

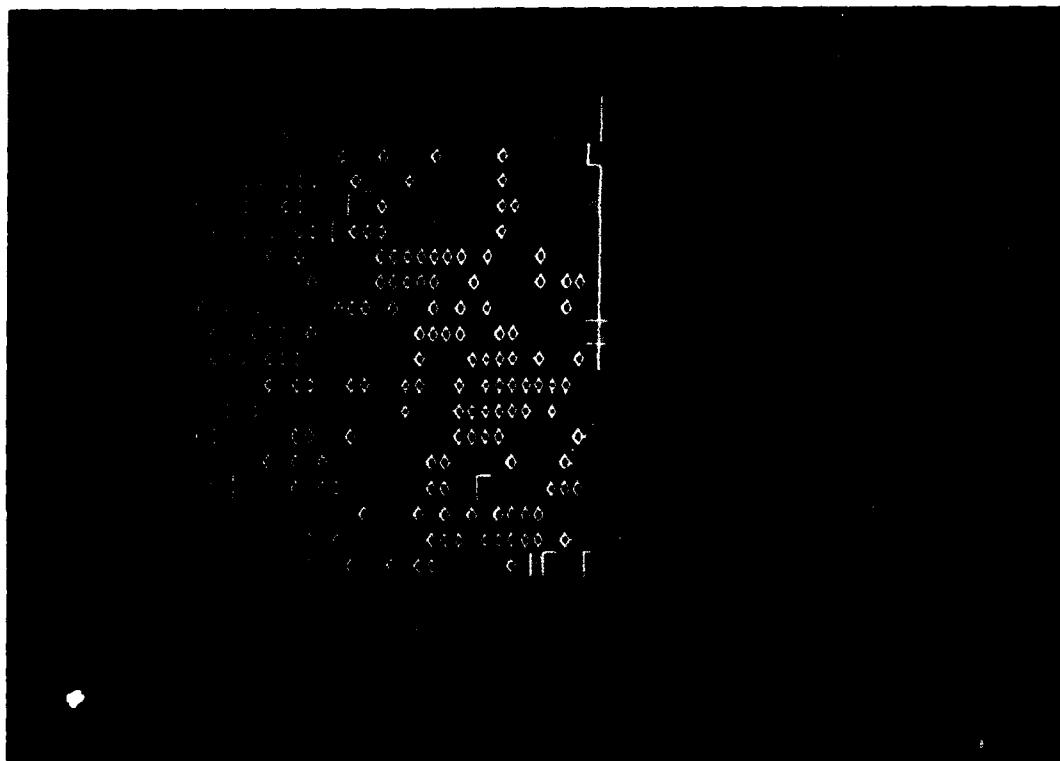**FIGURE 2   DETAILED HISTOGRAM PLOT OVER SELECTED DATA RANGE**

FIGURE 3 GREY SCALE MAP OVER FULL DATA RANGE

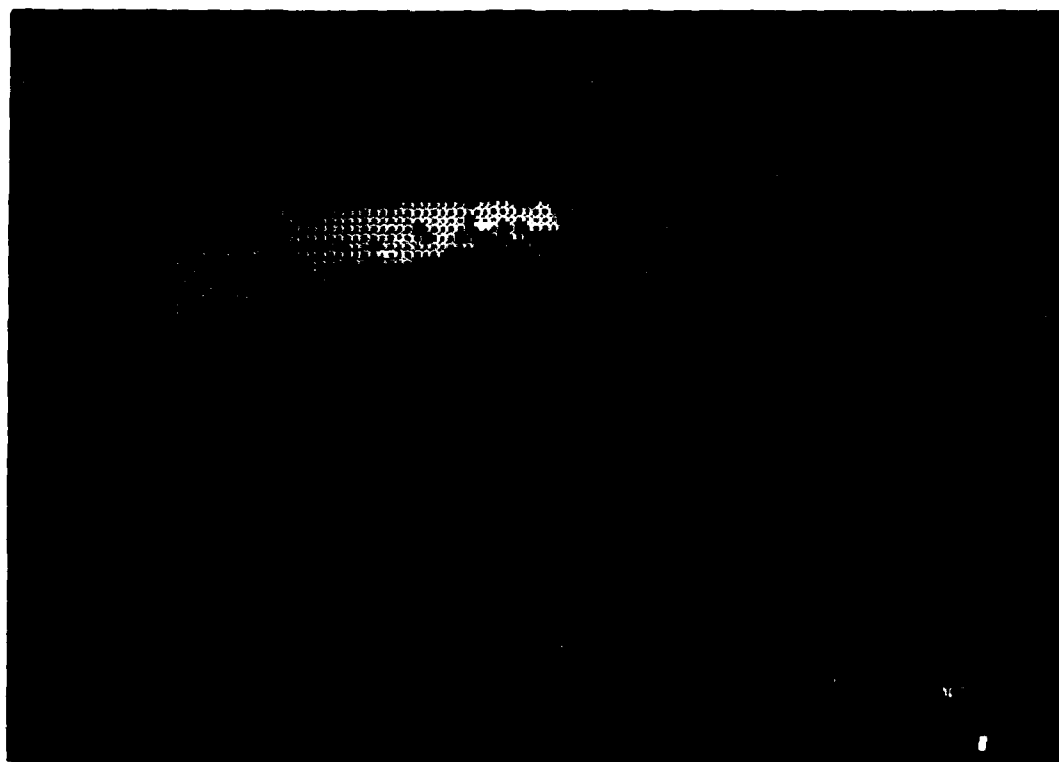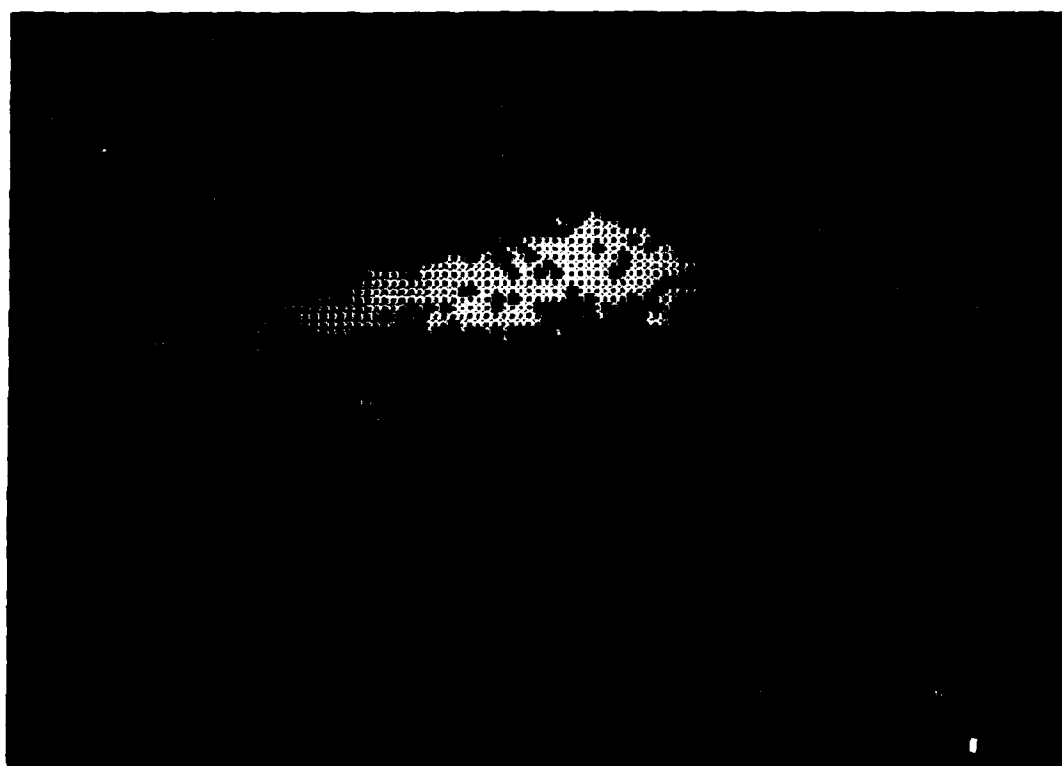**FIGURE 4 GREY SCALE MAP, DATA RANGE FROM 10 mA TO 80 mA**

FIGURE 5   GREY SCALE MAP, DATA RANGE FROM 30 mA TO 40 mA

FIGURE 6   EXAMPLE OF FAILURE MAP

FIGURE 7   FET SELECTION MAP FOR I_{DSSO} RANGE 20 mA TO 30 mA

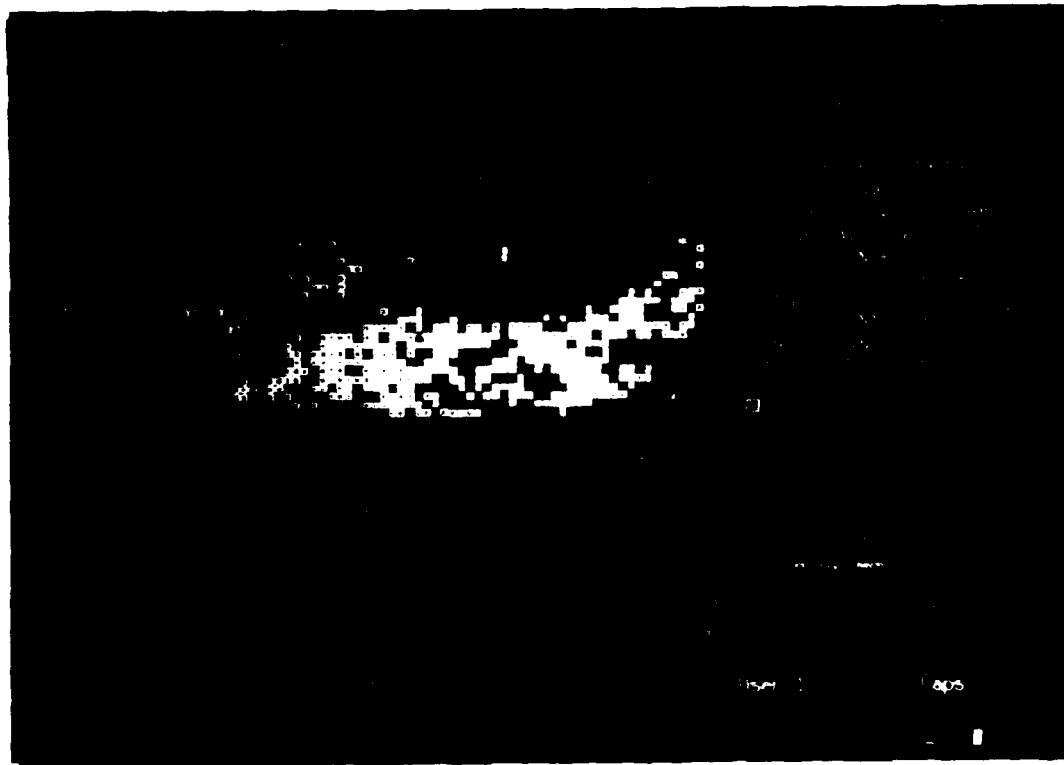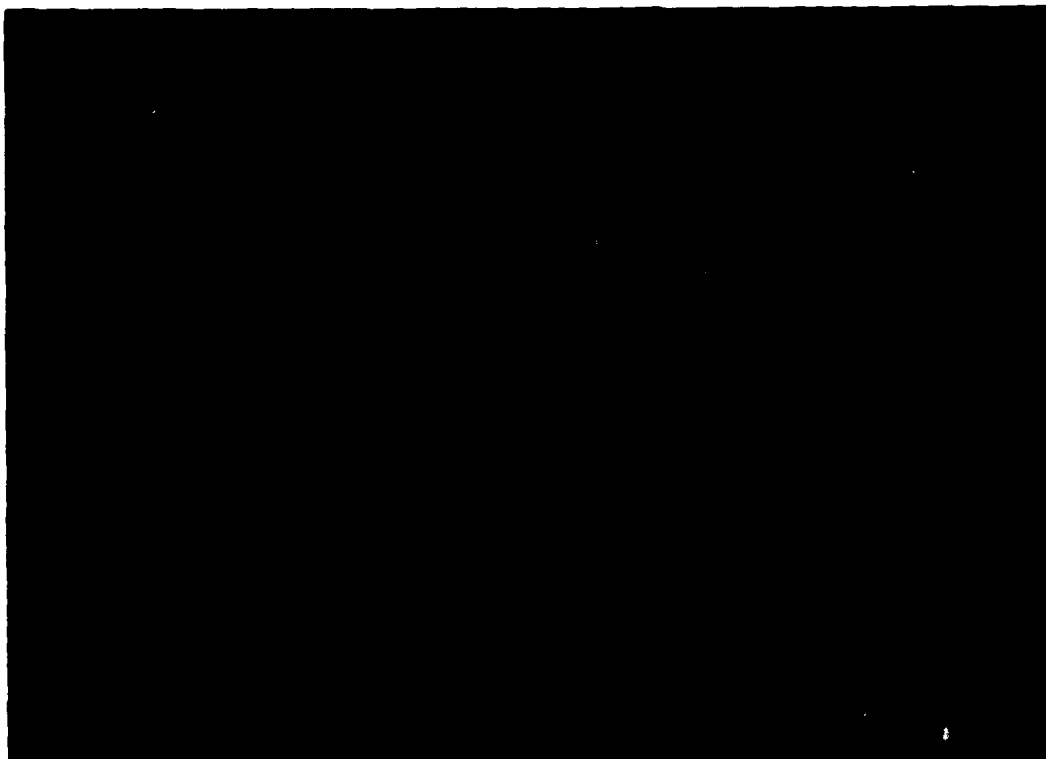FIGURE 8   FET SELECTION MAP FOR I_{DSSO} RANGE 30 mA TO 40 mA

FIGURE 9   FET SELECTION MAP FOR I_{DSSO} RANGE 40 mA TO 50 mA
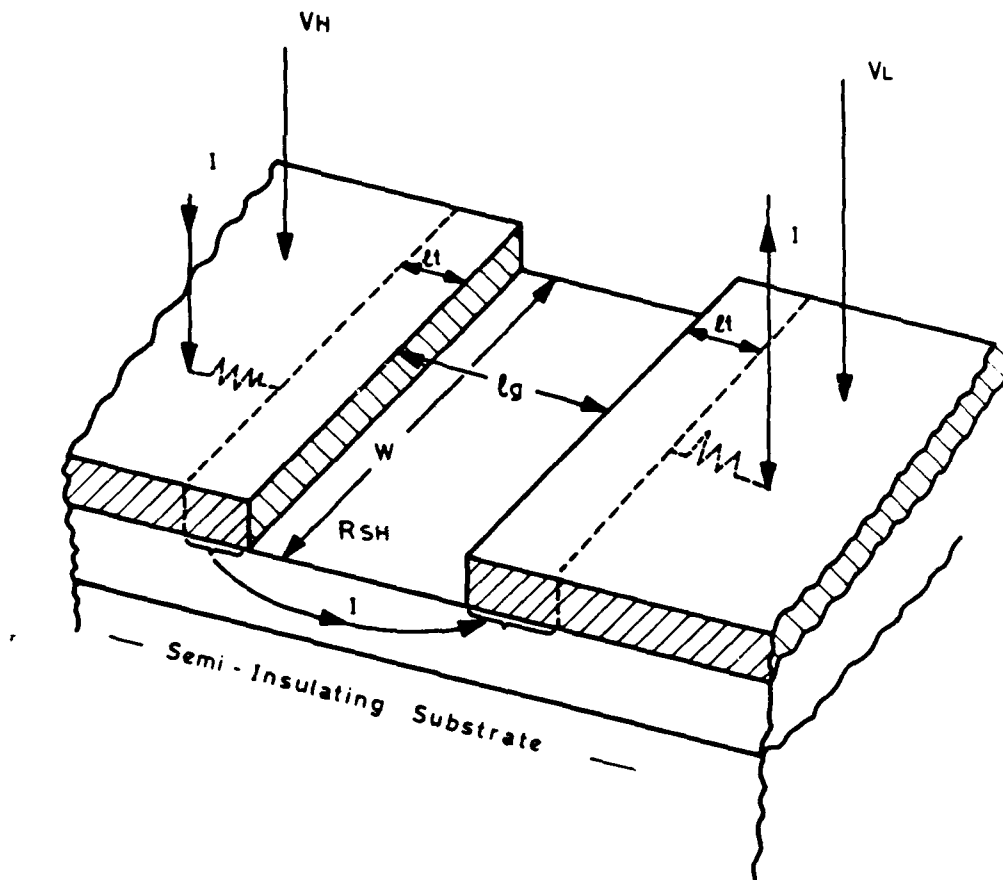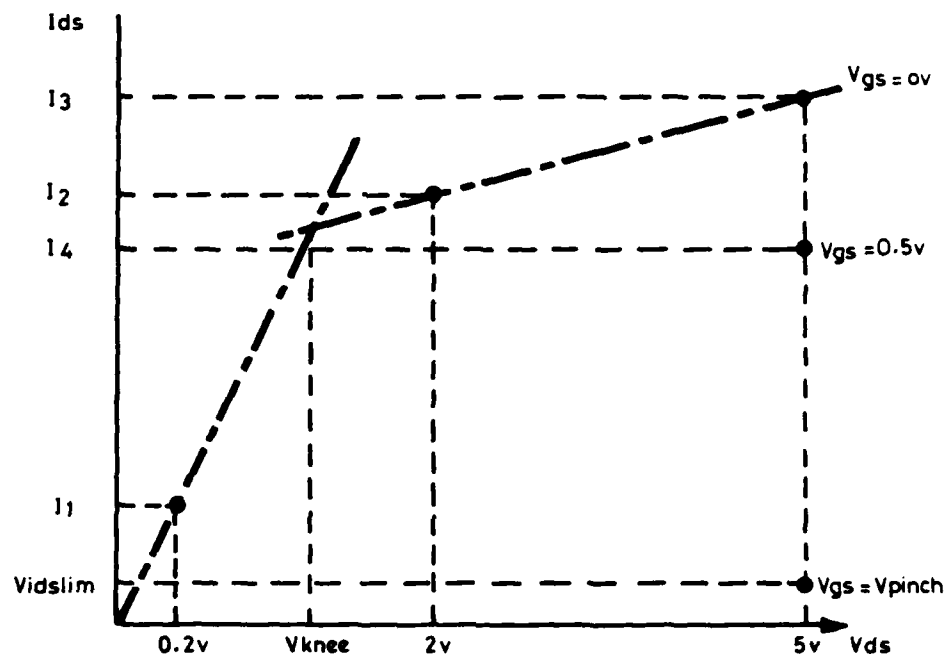
FIGURE 10   TYPICAL SCATTER PLOT
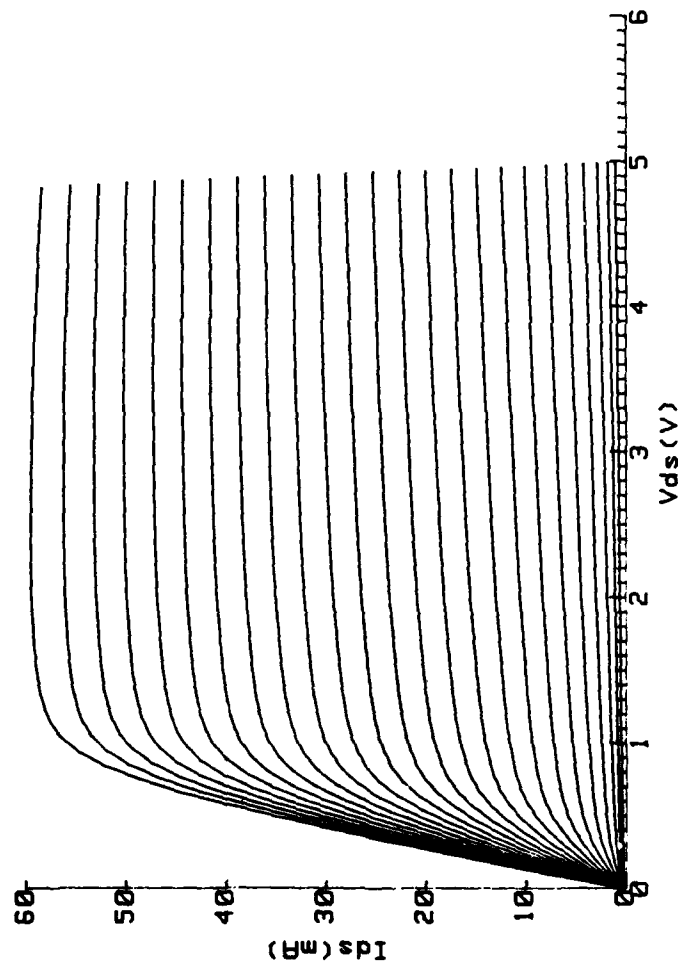
FIGURE 11   CONTACT RESISTANCE MEASUREMENT

$$R\,slope = \frac{0.2}{I_1} \quad : \quad Gd = \frac{(I_3 - I_2)}{5 - 2} \quad : \quad Idsso = I_3$$

$$gm = 2(I_3 - I_4)$$

FIGURE 12   DEFINITION OF MEASURED FET PARAMETERS

13 Jul 1987   EPI LAYER MA514 FET100 NO 4611

F1004611V
IDS/VDS CURVE

RSLOPE=13.36 OHM
IDSS0 =58.32mA
GD   =.01mS
VKNEE =.7844V
GM   =28.09mS
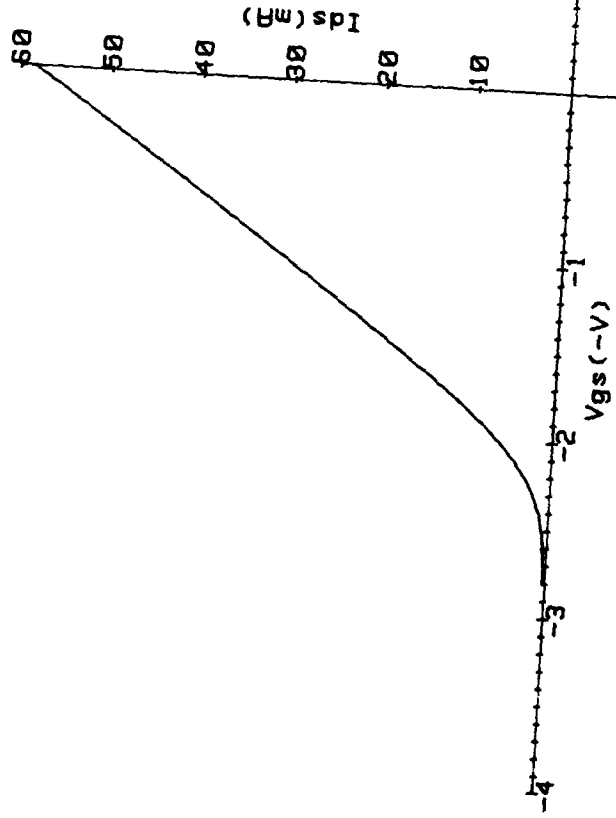IGATE =.095uA
IDSS4 =.009mA
VPINCH=1.6V

VOLTAGE STEP=.1V

Probed by:-BTH
Probed on:-04/11/86
     TIME:-11:18:06
     -DP2 DIVISION-
     -RSRE MALVERN-

Ids(mA)

Vds(V)

FIGURE 13   DETAILED FET CHARACTERISTICS, I_{DS}/V_{DS} PLOT

13 Jul 1987   EPI LAYER MA514 FET100 NO 4611

F1004611V
Ids/Vgs PLOT

VDS=5V

Ids(mA)

60
50
40
30
20
10

-4   -3   -2   -1

Vgs(-V)

+Probed by:-BTH
+1Probed on:-04/11/86
      TIME:-11:22:14
     -DP2 DIVISION-
     -RSRE MALVERN-

FIGURE 14 DETAILED FET CHARACTERISTICS I_{DS}/V_{GS} PLOT

14 Jul 1987   VARACTOR ONLY AREA 2500 Sq. microns

VAR1BbI
DIODE I/V PLOT

DEVICE:-1 1
IDEALITY FACTOR=1.2
BARRIER HEIGHT =.694
RESISTANCE=1.11 Ohm
INTERCEPT=2.07E-11A
AREA=2.5E-5cm^2

MANUAL CURVE FIT

Probed by:-BTH
Probed on:-09/04/87
    TIME:-16:21:45
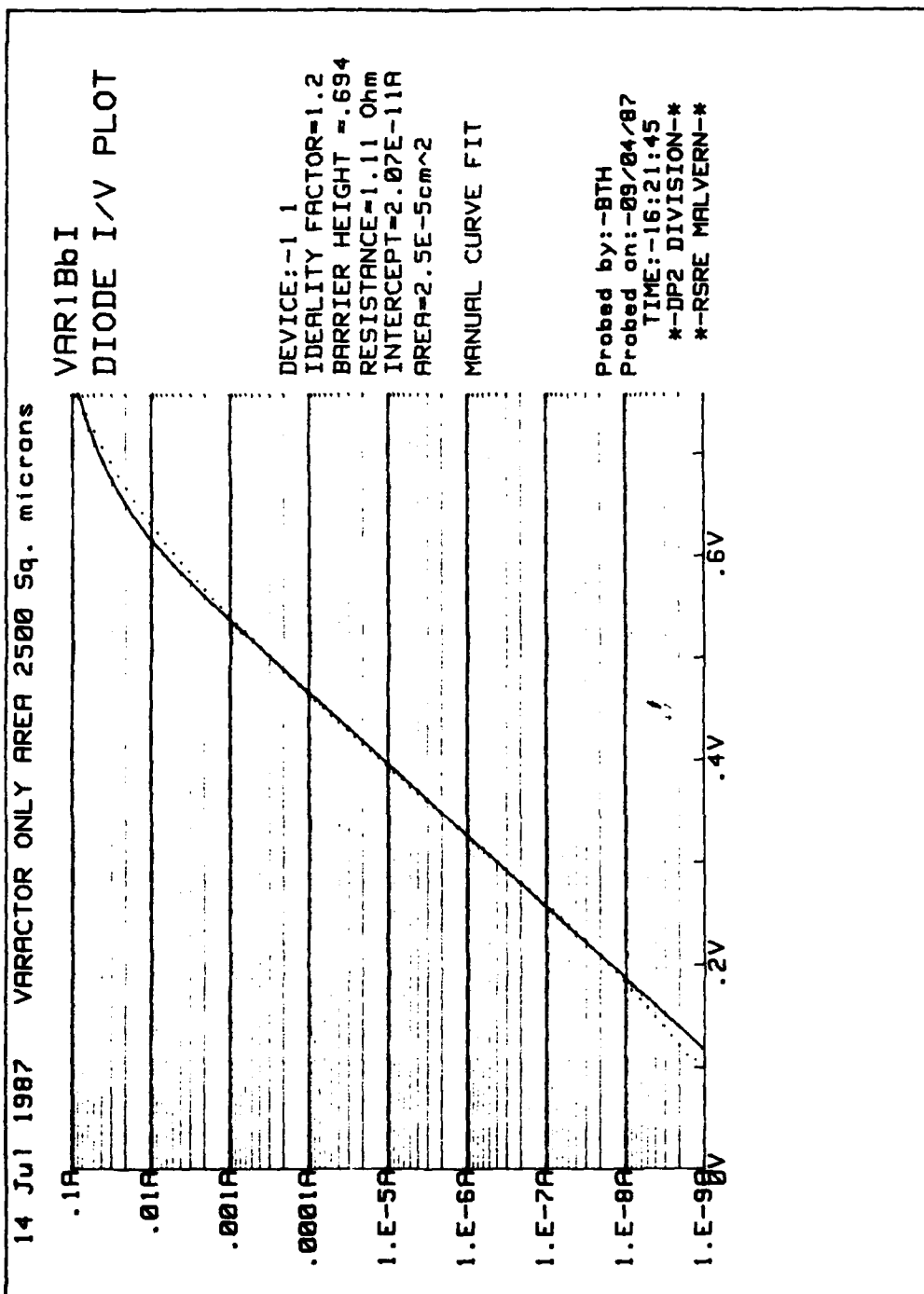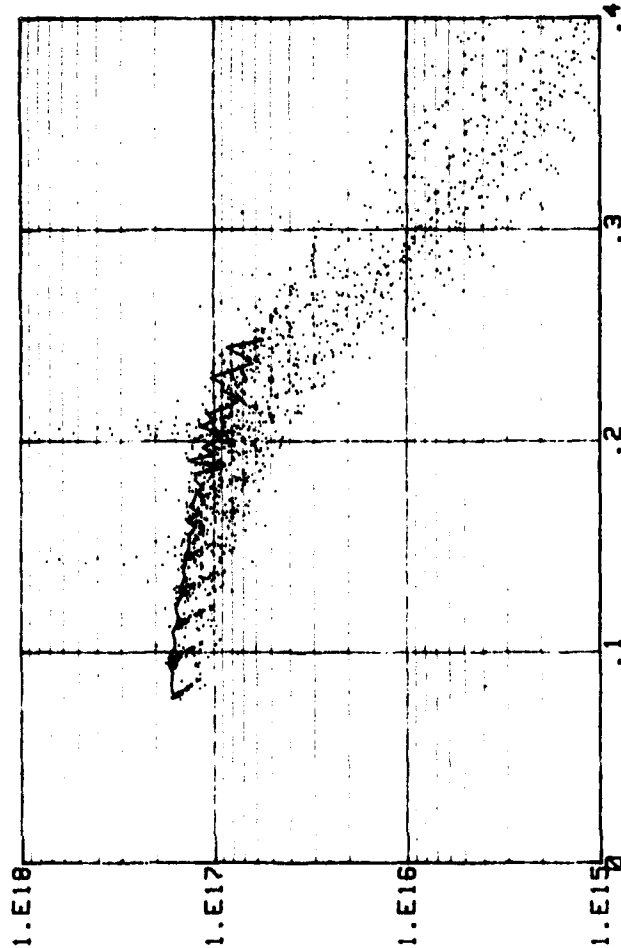*-DP2 DIVISION-*
-RSRE MALVERN-

FIGURE 15 DIODE FORWARD CHARACTERISTIC PLOT

27 Jul 1987   RH FATFET ON MMT78 26EBT EVERY FOURTH DEVICE

MT7826P

Nd PROFILE

DEVICE NUMBER
16 16
Nd/cc
Plotted against
Depth(Microns)

ETCH:-0uM

FREQUENCY:-.01MHz
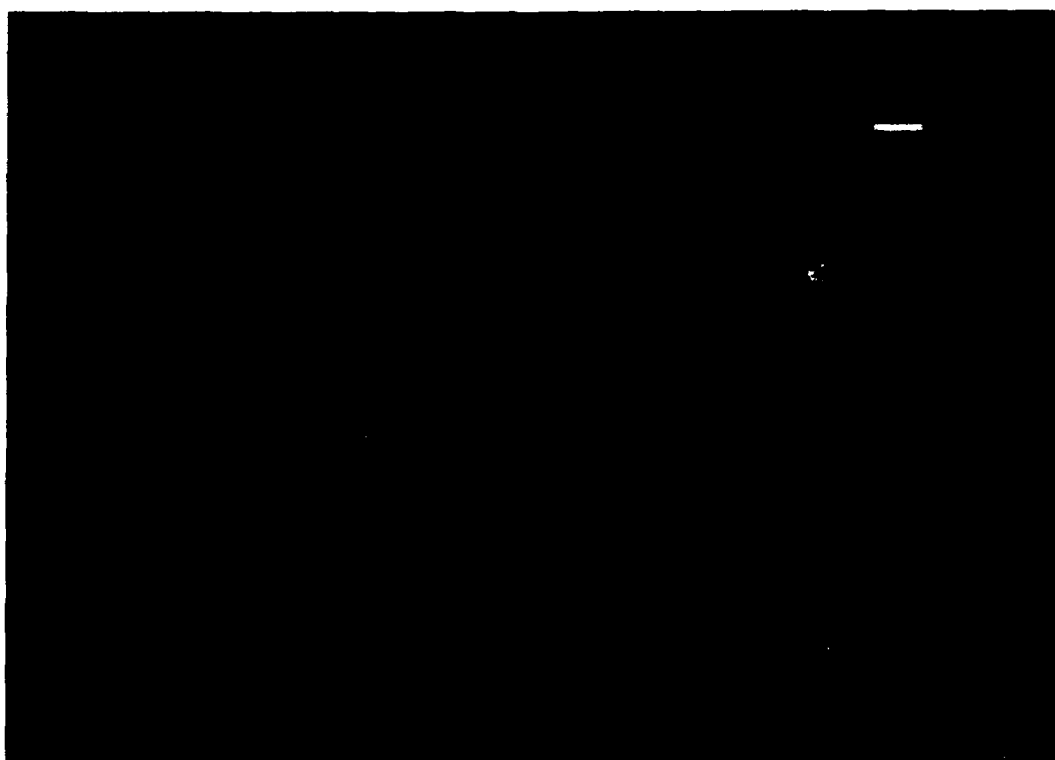AREA:- .00015cm^2

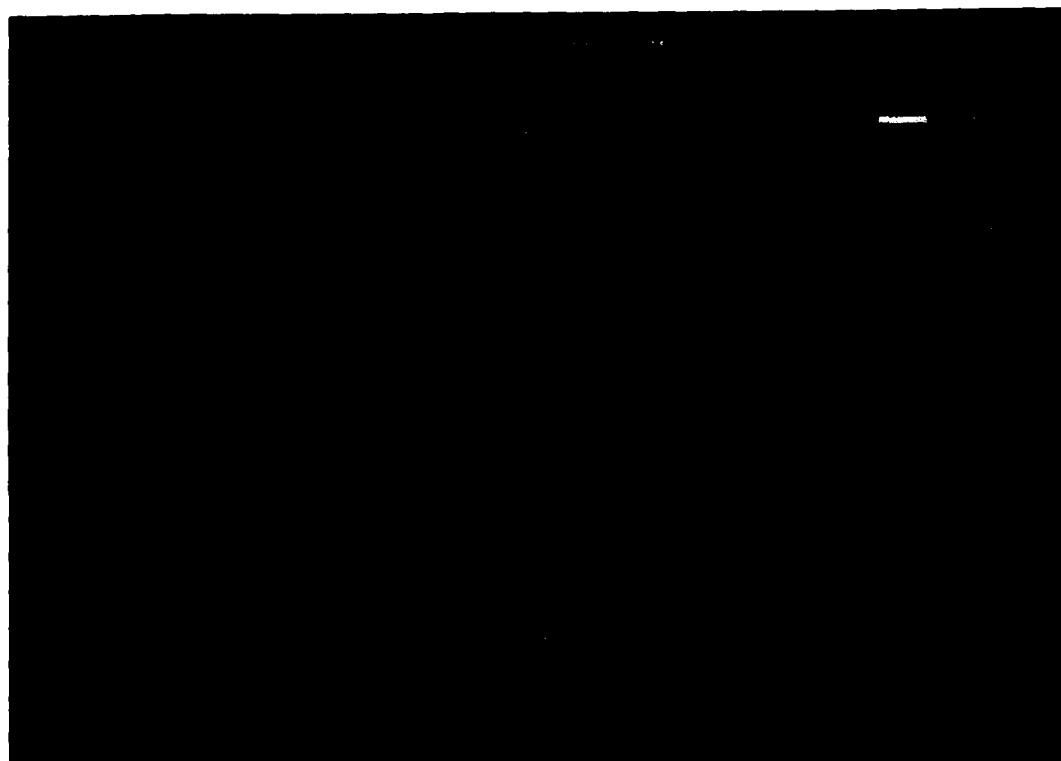Probed by:-BTH
Probed on:-07/05/86
TIME:-14:33:02
-DP2 DIVISION-
-RSRE MALVERN-

FIGURE 16 OVERLAY OF FATFET C/V PROFILES

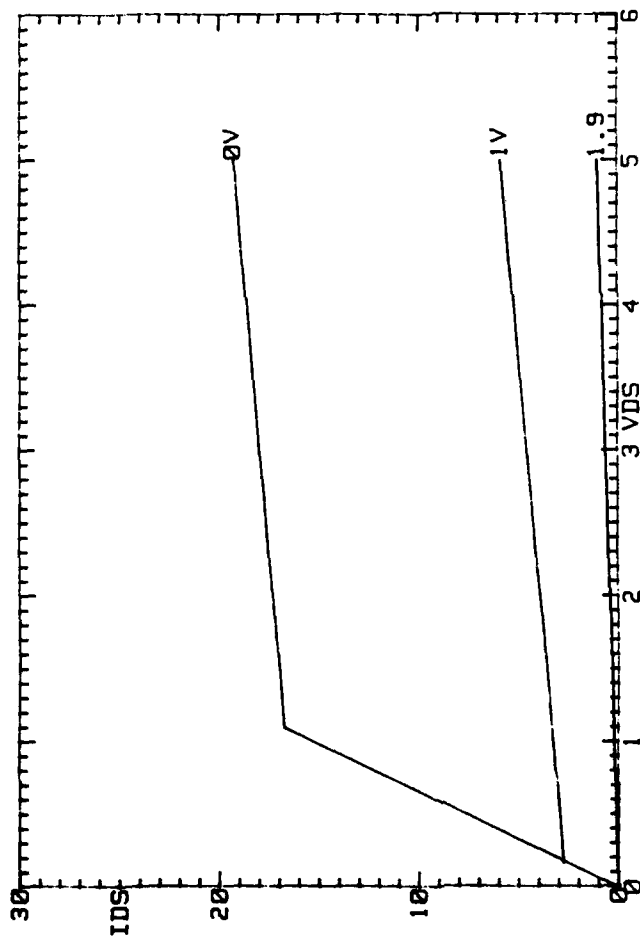FIGURE 17   EXAMPLE OF MENU DISPLAY BEFORE A DATA FILE HAS BEEN SELECTED

FIGURE 18   EXAMPLE OF MENU DISPLAY AFTER A DATA FILE HAS BEEN SELECTED

21 Aug 1987   LH MFET ON REF1 (PUN 8061 Z034)
DIAGRAMMATIC ONLY

LMFETF
IDS/VDS CURVE

COLUMN:-7 ROW:-4
RSLOPE=61.1 OHM
IDSS0 =19.28mA
GD   =.6521mS
VKNEE =1.1V
GM   =13.41mS
IGATE =3.263uA
IDSS4 =.004mA
VPINCH=1.9V

Probed by:-BTH
Probed on:-13/03/86
    TIME:-14:10:41
-DP2 DIVISION-
-RSRE MALVERN-

FIGURE 19   EXAMPLE OF DIAGRAMMATIC I_{DS}/V_{DS} CURVE OF FET OBTAINED IN
SELECTION MAP MODE

24 Aug 1987   V PINCH SET AT 20 MA
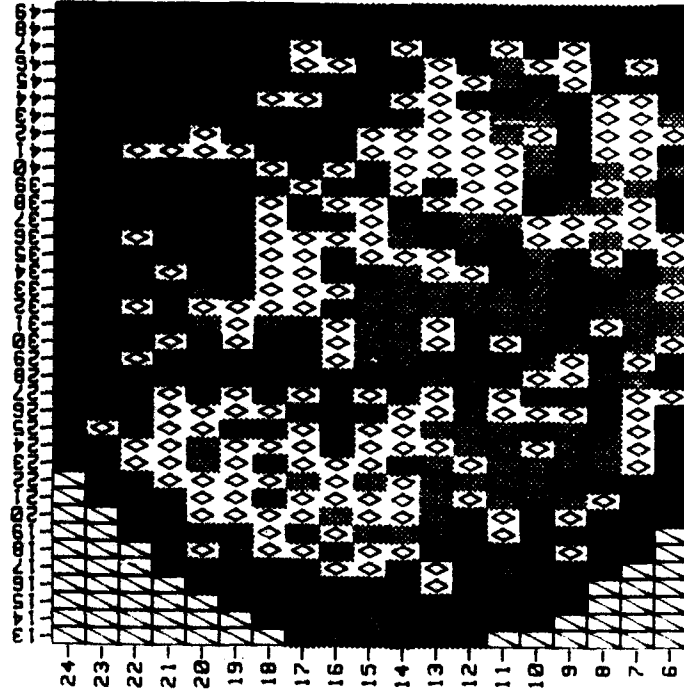
FET102AF
FAILURE MAP

o :- INVALID DATA
⊠ :- OFF WAFER
R=RSLOPE >500 OHM
S=SHORT <1 OHM
I=IDSS0 >200 mA
D=Gd FAIL
K=VKNEE >3 V
T=Gm <.2 mS
G=GATE I >100 uA
V=VPINCH >4V @20mA
◇DEVICES PASSED

Probed by:-JTP
Probed on:-02/06/87
TIME:-09:47:15
-DP2 DIVISION-
-RSRE MALVERN-

FIGURE 20 PLOTTER COPY OF FAILURE MAP USING CHARACTERS

FIGURE 21 PLOTTER COPY OF FAILURE MAP USING COLOURED RECTANGLES AND SHADING
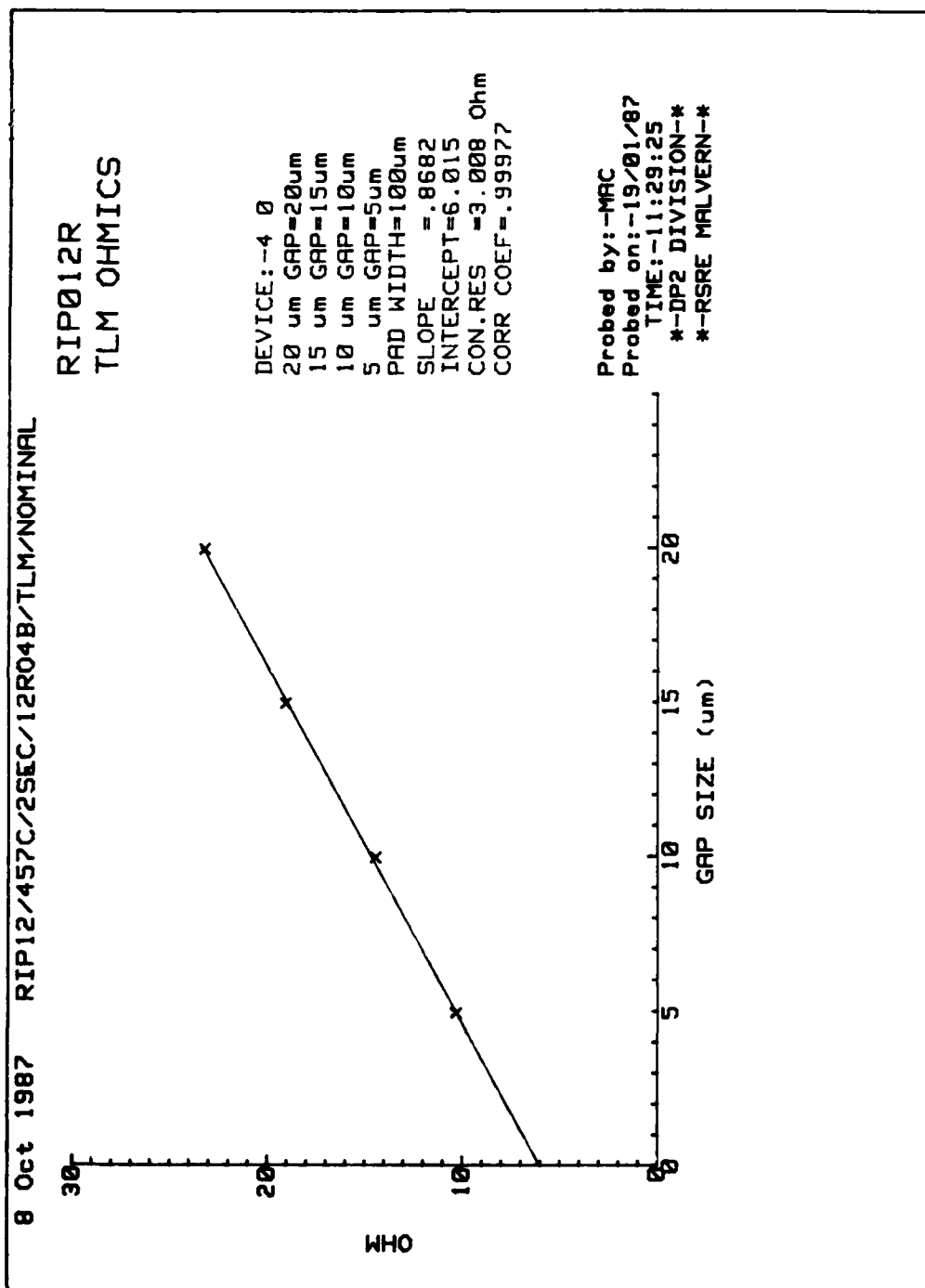
FIGURE 22 PLOT OF INDIVIDUAL TRANSMISSION LINE OHMIC MEASUREMENT, SELECTED FROM WAFER MAP
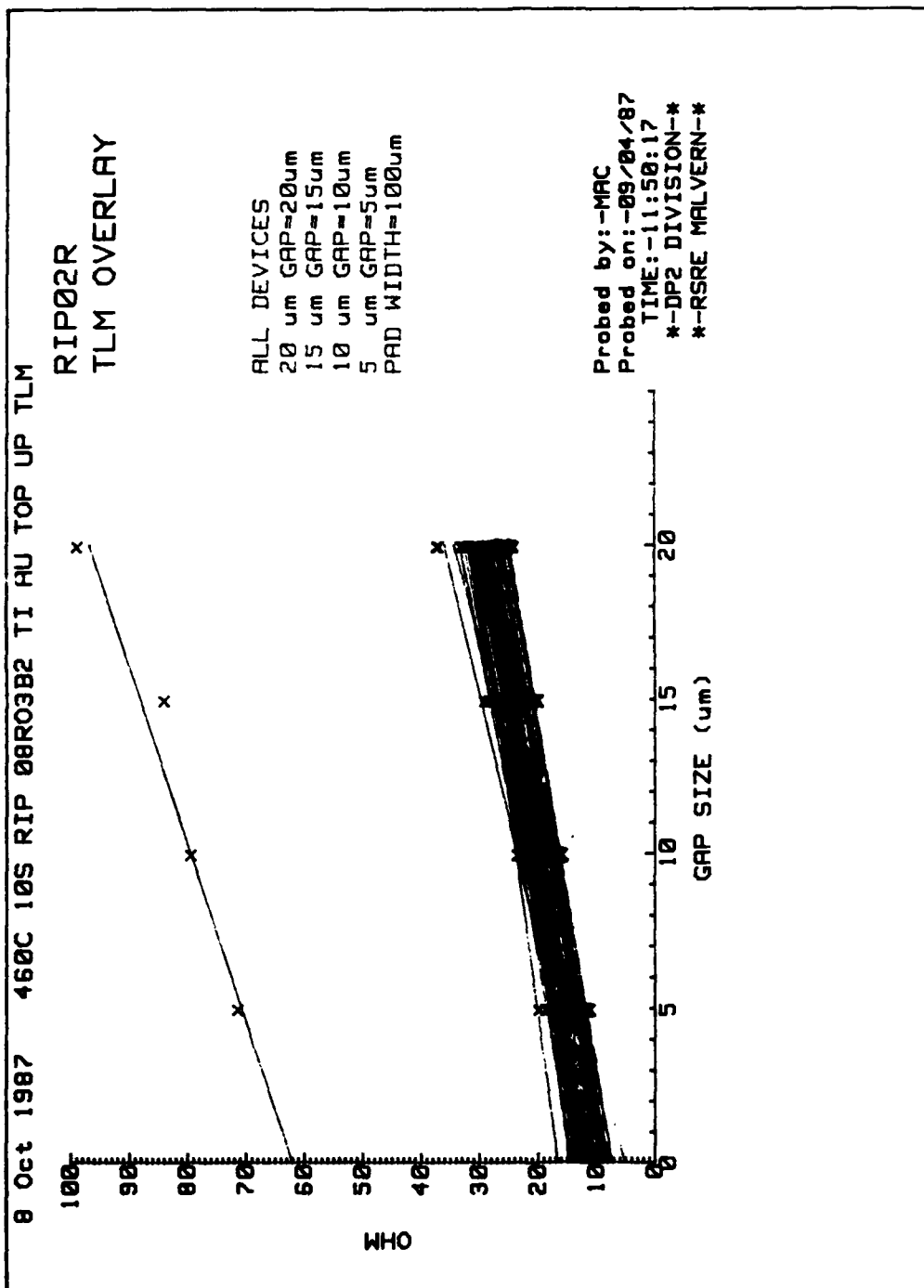
FIGURE 23   PLOT OF TRANSMISSION LINE OHMIC MEASUREMENTS FOR WHOLE
            WAFER

DOCUMENT CONTROL SHEET

Overall security classification of sheet ...... UNCLASSIFIED ....

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classified information, the box concerned must be marked to indicate the classification eg (R) (C) or (S))

1. DRIC Reference (if known)	2. Originator's Reference MEMO 4066	3. Agency Reference	4. Report Security Unclassi-Classification fied
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5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location		

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            PART 2.   THE DATA SORTING & DISPLAY FACILITY.

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers)   Title, place and date of conference

8. Author 1 Surname, initials HUGHES B T	9(a) Author 2 AVERY B E	9(b) Authors 3,4...	10. Date 1987. 07	pp. ref.
11. Contract Number	12. Period	13. Project	14. Other Reference	

15. Distribution statement

Descriptors (or keywords)

continue on separate piece of paper

Abstract
The Automatic Device Probing System used in the Microwave Devices Division (DP2)
comprises separate measurement and data handling facilities. The measurement
facility is described in RSRE Memorandum 4065 and the data sorting and display
facility forms the subject of this memorandum.

The facility described is designed to assist in analysing the large quantity of
measured data obtained from device wafers and allows general trends as well as
individual device parameters to be investigated. Programs have been written to
produce maps which allow parameter variations across wafers to be assessed and
additional routines are available which present the data in histogram form.

                                    Continued overleaf ...

S80/48

Abstract from Memo 4066 continued.

These options allow the numeric as well as the geographic distribution of
the data to be investigated. Three main types of map display are available,
these display the variation in magnitude of a device parameter across a wafer,
the location and nature of the failure of any failed devices and the location
of devices with a specified combination of parameters. The histogram programs
allow the data range and class interval to be adjusted enabling estimates of
yield and process control to be made. For measurements such as Capacitance/
Voltage on Schottky test patterns or current/voltage on active devices plots of
the measured data can be displayed. Routines are available which allow curve
fitting to the measured data so that barrier heights etc can be extracted.

Full use has been made of colour and grey scales in order to maximise the
visual content of the information presented on the display screen and all
display modes are easily selected using a combination of menus and softkeys.